THE BOOK WAS DRENCHED

ENGINEERING

WITH

ENGINEERING WITH RUBBER

Frontispiece. Typical of rubber's diversified industrial application is this Torsilastic rubber spring, which can be engineered to serve as the suspension member for thousands of industrial, commercial, and automotive uses including stationary motors, industrial trucks, office chairs, railroad coaches, passenger cars, trucks, busses, airplane landing gear, farm implements, drilling equipment, seats of all types, door hinges and springs, streetcars, motorcycles, physical-exercising equipment, truck tail gates, wagons, bicycles, and even built-in ironing boards and rocking chairs.

ENGINEERING WITH RUBBER

Edited by

WALTER E. BURTON

IN COLLABORATION WITH ENGINEERS AND RESEARCH MEN OF THE B. F. GOODRICH COMPANY

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ENGINEERING WITH RUBBER

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PREFACE

When a man sets out to build and market a new product—a machine for removing dents from automobile fenders, for example—he may decide that some rubber parts are needed. He finds it necessary, therefore, to know some of the engineering, application, and design principles involving rubber hose, gaskets, and molded pieces of rubber. In looking about for information, he can pick up a helpful fact here and there from manufacturers' pamphlets, folders, and booklets; but sometimes he gets lost in a maze of words and pictures. Perhaps he consults the engineering department of some rubber manufacturer; but, more likely than not, he goes ahead with his designing, making what he thinks are the proper provisions for whatever rubber parts he expects to include. Then, much too late, he establishes contact with rubber technicians and learns that he will have to make radical changes in design in order to take advantage of their recommendations.

To help eliminate this confusion, the editor collaborated with The B. F. Goodrich Company, Akron, Ohio, to gather material for a book dealing with industrial rubber products and their application to industrial uses. This volume is the result. It summarizes, in convenient form, much of the miscellaneous information that was scattered through countless folders, booklets, catalogue pages, price sheets, and the minds of technicians. It provides basic information to start the reader on the right track and to induce him, if he happens to be a product designer, to consult with rubber men in the early blueprint stage of a new product. In order to obtain a clear idea of what design engineers and others would like to see in such a volume, an extensive mail survey was conducted and manufacturers were visited personally. Many of the ideas and suggestions that they contributed have been included in this text.

The book deals with specific subjects, such as kinds of rubber and their properties, adhesives, latex products, belting, hose, molded and extruded parts, coverings and linings, gaskets, sponge rubber, hard rubber, and rubber mountings. The more important American-made rubbers, formerly classed as "synthetic rubber," are included, as are some nonrubber materials such as plasticized polyvinyl chloride.

The book contains basic information on physical and chemical proper-

ties of various rubber compounds, structural details of industrial rubber products, and typical dimensions. Because of the continuous, rapid growth of rubber science and engineering, many of the precise values in this book may be subject to modification from time to time.

It might seem that such a book would make it less necessary for the potential user of industrial rubber to consult a rubber technician or manufacturer for assistance in planning a new product or application. On the contrary, one of the book's objectives is to urge designers of new equipment involving rubber or plastics to get in touch with manufacturers of such materials as early as possible. It is easier and cheaper to change a product design while it is still in the blueprint stage than when all the dies and jigs have been made.

The preparation of this book was not a one-man job. Nothing much larger than a technical bulletin or pamphlet would have resulted without the cooperation of the research, engineering, technical, and sales staffs of The B. F. Goodrich Company, associated organizations, and other persons and concerns who are mentioned in the text. Among those who have given valuable assistance are Dr. H. E. Fritz, A. W. Carpenter, Dr. W. L. Semon, Dr. H. L. Trumbull, Dr. R. V. Yohe, A. E. Juve, A. S. Krotz, C. W. Staacke, J. M. Flounders, R. O. Hendrix, H. J. Flikkie, W. L. Smith, M. O. Orr, B. S. Taylor, H. H. Fink, E. B. Busenberg, L. H. Chenoweth, B. E. Kline, N. P. Singleton, P. W. Van Orden, C. F. Conner, Jay E. Miller, W. A. Smith, G. K. Ryan, J. E. Thomas, H. F. Mosher, H. C. Klein, A. C. Lutz, G. T. Parsons, F. L. McNabb, H. S. Meyer, B. W. Carson, G. H. Stewart, J. W. Dunn, C. W. Brees, E. M. Thorp, H. J. Mitchell, A. M. Fiala, R. S. Price, P. G. Cooper, W. F. Reach, K. B. Kylander, and P. L. Kline.

WALTER E. BURTON

AKRON, OHIO

CONTENTS

CRYSTAL GAZING

Thirty years or so ago, an executive of a large manufacturing concern was asked if the company's chemists and physicists would spend time and money investigating the synthesizing of rubber. "No!" he declared. "I'll wager there never will be a pound of synthetic rubber made in this country." But the researchers, thank goodness, went ahead with their studies. If they had not, the Second World War might have had a different ending.

The stuff we call "American rubber" looms large in any vista of the future. Scientists hesitate to make predictions about it. Its past performance has been disappointing in some respects, almost amazing in others. GR-S, the American rubber that saved our skins during the Second World War, has some important superior qualities but is not a duplicate of crude rubber. Better compounds of the GR-S type may be expected. This will be but one beneficial result of the renaissance of competitive research. Wartime requirements made it necessary for manufacturers to pool their knowledge, so that competition in research practically disappeared. But with the return of scientific rivalry, we can expect a formidable outpouring of better, more economical materials and products.

The group of American rubbers known as Nitril is in its infancy. Oil resistance is an outstanding property and is assurance enough that the Nitrils are here to stay. Nitril compounds can be made to such levels of toughness that no present-day machinery can handle them adequately. So we may look forward to considerable advancement in the design of rubber-working machinery.

New adhesives are being developed constantly in the rubber industry. Cements that rival solder in holding metal parts together are already here, but they are only hints of what may come. It is possible to cement a tungsten carbide cutting tip in its mild-steel holder for use in machining hard, tough metal at high speed on a lathe. So why should it be absurd to imagine that someday, washing machines and carpet sweepers and even motor cars may be fastened together with cements instead of bolts and rivets? Automobiles of the future probably will use brake linings that are cemented to the shoes instead of being riveted. Three times the life of

riveted linings will be one of the benefits. The cement used must be able to retain its grip at red heat!

For the first time in history, rubber technicians now understand enough about rubber pigments to permit some cheerful speculation about color. In recent years, carbon black was the leading pigment and was excellent for black and similar dark-colored rubbers. But white or light-colored rubber could not be made if carbon black was present, and other pigments would not impart the toughness attained with carbon black but instead often weakened the compound structure. Fumed silica, a "white carbon-black" pigment, is expected to eliminate this condition if it can be made commercially available. It permits rubber compounds to be made in a wide range of colors, including brilliant hues and pastel tints, without weakening the compound structure. The possibilities are unlimited: long-wearing rubber floor, wall, table, and counter covering in unlimited colors; longer life for colored hot-water bottles, tubing, hose, and hundreds of other products; possibilities of using color codes for rubber parts involved in machine assembly; colored rubber products and elements to match paint schemes; better colored wire insulation; more cheerful hospital accessories; etc.

Present-day rubber-fabricating practices often seem to incline toward the primitive. For instance, rubber tank linings are applied by hand, like so much wallpaper. Such conditions are no reflection on the progressiveness of the rubber industry but are merely indications that the technique is at an intermediate milepost and not at the end of the road. In the rubber industry as in any other, progress is built upon a gradual, time-consuming accumulation of experience and knowledge. So as time goes on, we can expect better and cheaper ways of making articles of rubber and rubberlike plastics.

To some people, the trend toward the establishment of huge, costly research laboratories by the rubber and various other industries may seem to be evidence that scientific development is being regimented. The outsider may imagine that the boss says to a research chemist, "Here, George, get busy and work out a new rubber that can be made from molasses. Gotta have it by a week from next Tuesday." But that is not quite the way work is carried on in the typical industrial research laboratory whose program is devoted mostly to the accumulation of fundamental knowledge.

For one thing, it is not an easy matter to predict what a research scientist will discover or when he can be expected to synthesize some badly needed material. Consider the case of crude rubber: So far, no one has succeeded in making a true synthetic rubber. For a good many years, various investigators have been trying to synthesize natural rubber—to

make, in the laboratory, a substance that has exactly the chemical composition and all the properties of the basic crude-rubber hydrocarbon. But to date, they have only come close to the target by making some rubberlike synthetics that are highly useful but still are not duplicates of crude rubber.

However, some of these days, someone who may be a brilliant scientist trying to develop a better adhesive in a multimillion dollar laboratory or a sophomore rushing through his chem lab chores so he can go out and play tennis will uncover a way of synthesizing natural rubber. Then will come a revolution, just as the discovery of synthetic indigo worked a modest transformation in the dye industry.

Impure indigo used to be obtained laboriously from tropical plants. The discovery of a way of synthesizing it from aromatic amino compounds made plant collecting unnecessary and brought the price down to a point where everybody can enjoy products colored with indigo dye. And the synthetic indigo is superior to the natural because the impurities are left out.

A parallel condition may develop when crude rubber is synthesized. Many of the shortcomings of present-day tree rubber stem from the impurities that cannot be eliminated from it. Yet despite this, crude rubber is superior to the synthetics in some important respects. When the rubber industry learns how to duplicate crude rubber in the laboratory and factory, it will know also how to leave out the troublesome impurities. This will open the way for product improvement that will make life better for everyone who uses rubber in any form. Probably some tree tappers will seek new work, and some ships will find other cargoes to haul, but rubber products will be better and cost less—and another war will not catch us with our stockpiles down.

Even if no one manages to synthesize rubber, we can expect more widespread use of the materials we already have. Inexpensive rubber paving bricks or slabs, latex foam mattresses to make dairy cows even more contented, American rubber tough enough to withstand red heat—these are only samples of what may be commonplace products before long.

Chapter 1

TYPES OF RUBBER

As more than one student of history has observed, this continent is fortunate because it derived its title from the first half of Americus Vespucius' name instead of the last. One of our biggest industries got an equally lucky break when, in 1770, Joseph Priestley found that a mass of caoutchouc such as Columbus had brought from the New World would rub out pencil marks and thereupon dubbed the stuff "rubber."

Today, the word "rubber" perhaps should have attached to it a little tag explaining precisely what it means. In a strict sense, the term refers to a hydrocarbon of vegetable origin, having the empirical formula $(C_5H_8)_x$. But it has become common practice to apply the word "rubber" to the materials forming a large assortment of finished products such as overshoes, tires, office bands, floor covering, pencil erasers, garden hose, and belts. It would be more accurate to say "rubber compounds" when referring to such materials, but most people simply say "rubber."

Therefore, in nearly all instances, when someone talks about rubber, he is referring not to a single, definite material but to a thousand materials, each varying from the others according to the compounding ingredients combined with the basic hydrocarbon. It is important that the product designer and engineer keep this in mind, for difficulties sometimes arise because attempts are made to fence in rubber with a definite set of properties like those applying to an element such as iron. Rubber in industry is practically always compounded with other chemicals, each of which influences the properties of the resulting material. Since the combinations are limitless in number, the properties of rubber compounds may be considered as infinite.

For practical purposes, a "rubber" may be defined as a material that is capable of being stretched or otherwise distorted to a considerable extent and then retracting quickly to nearly its original dimensions. This definition is used as a handy test to determine whether a material can be classed as a rubber, sometimes called an elastomer.

Crude (Natural) Rubber

Crude rubber is found in the juices of many plants, including the shrub guayule, kok-saghyz or Russian dandelion, goldenrod, milkweed, cryptostegia, and dozens of other shrubs, vines, and trees. But the principal source of the best rubber latex is the tree *Hevea brasiliensis*, which is a native of Brazil and flourishes in both the wild and cultivated states. Seeds of this tree were used to start the extensive plantings throughout the Far East, which became the world's chief source of crude rubber.

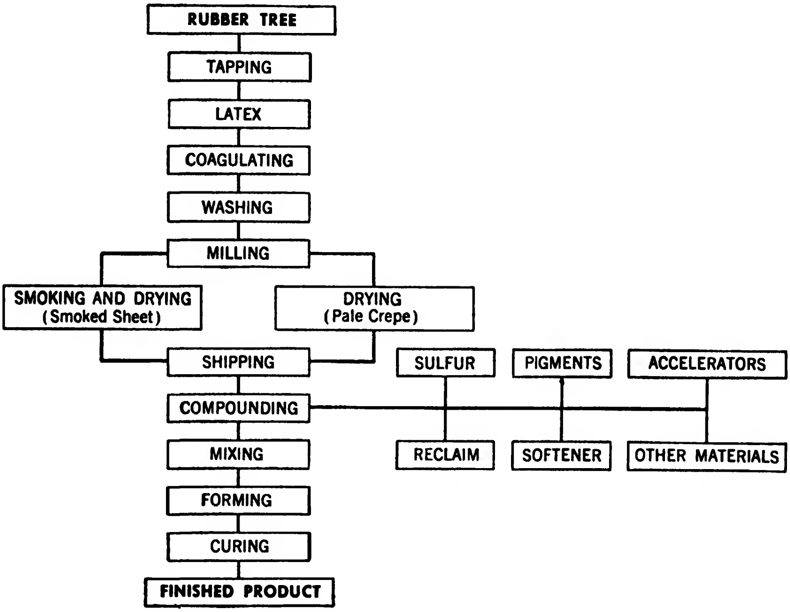

Fig. 1. Flow diagram for crude rubber.

Crude rubber possesses properties both good and bad, which must be considered when using it in industrial products. In the unvulcanized condition, it is a good adhesive and is therefore useful in cements. The outstanding characteristic of soft vulcanized rubber is its ability to return immediately to its original form after being extremely distorted—its elasticity, in other words. Other main characteristics of crude rubber compounds may be summarized as follows:

It is a good electrical insulator, the dielectric strength ranging from 100 to as high as 550 volts per 0.001 inch of thickness. Rubber compounds that conduct electricity are now being used.

Elongation of vulcanized rubber ranges from 1 to 1,000 per cent.

Rubber compounds, except sponge, are practically noncompressible, being in this respect comparable to water.

Rubber compounds store energy to a greater degree than any other materials, being about 150 times better at this than spring-tempered steel.

Vulcanized compounds vary in density, but they average about 23 cubic inches to the pound.

Rubber compounds ordinarily oxidize slowly in air, and this action is hastened by heat and light.

Fig. 2. Tapping a rubber tree on a plantation. The latex collects in the cup visible on right side of trunk.

Vulcanized compounds can be made resistant to most inorganic acids, alkalies, and inorganic salts and to many organic chemicals.

The coefficient of expansion for rubber vulcanizates is usually higher than for metals.

Coefficient of friction between vulcanized rubber and dry steel is high, sometimes exceeding 1.0. Water acts as a lubricant, reducing the coefficient under some conditions to as little as 0.02.

Ordinarily, compounds will stand heat up to 150°F, but special compounds for particular applications will resist around 330°F.

Direct sunlight causes soft crude-rubber compounds to deteriorate. Some of this action can be offset by special compounding. Hard rubber is discolored slightly by sunlight, and its electrical surface resistivity is lowered.

Although crude rubber has a characteristic odor, most of the unpleasant

smells associated with rubber products are caused by some of the other compounding ingredients, such as low grades of reclaimed rubber.

Unvulcanized crude rubber dissolves in such solvents as gasoline, turpentine, carbon bisulfide, chloroform, benzol, solvent naphtha, and carbon tetrachloride. Vulcanized rubber swells in these solvents but does not dissolve.

Petroleum oils are natural enemies of rubber, causing it to swell and soften, but oil-resisting compounds that exhibit only moderate swell are in use. Castor and some other vegetable oils cause only slight swelling of any rubber compound, and glycerin, ethylene glycol, and plain water cause negligible swelling.

An inspection of this outline list of properties reveals that crude rubber has many good points, some bad ones. Aside from the fact that American rubbers duplicate some of the properties of crude rubber, man-made rubber and rubberlike materials continue in use because they possess properties (such as oil resistance) that make them superior to crude rubber.

Further details concerning the properties of crude rubber will be found in Chap. 2.

Reclaimed Rubber or "Reclaim"

Reclaimed rubber often is regarded as a cheap substitute for new rubber, but it is more accurately classified as a compounding material that frequently improves processability and the final properties of the product. The reclaiming of rubber for reuse is comparable, in the rubber industry, to the use of scrap steel and waste paper in those respective industries.

Rubber articles suitable for reclaiming after being scrapped include inner tubes, pneumatic and solid tires, shoes, boots, and mechanical rubber items. Reclaimed rubber is classified as: (1) alkali reclaims, which are the most important; (2) acid; and (3) heater. The process used in each case is dictated by the type of scrap.

In the alkali process used for reclaiming tire carcasses and the like, the scrap is ground into small pieces and cooked in 4 to 8 per cent (by weight) sodium hydroxide solution. The alkali destroys the cord or fabric present in the rubber scrap. The rubber itself undergoes some changes, including partial depolymerization, loss of elasticity and increase of plasticity, and removal of free sulfur. Solvents and softening oils are often added. The alkali is then washed out, the rubber mass strained to remove unwanted solids, and the reclaim is milled and formed into slabs for convenient handling. Later, it is used in rubber products, either as the only source of rubber hydrocarbon or along with crude or American rubber.

Reclaimed rubber contains around 45 to 65 per cent of the basic hydrocarbon (rubber), plus most of the compounding ingredients originally in the articles from which it was obtained. Reclaimed rubber first came into use because it was cheaper than new rubber. However, when crude was selling for 3½ cents per pound, reclaim, which then cost 4 to 5 cents per pound, accounted for about one-fifth of the rubber used. Reclaimed rubber possesses desirable properties other than its cheapness. Its advantages may be summarized as follows:

A mixture containing reclaim vulcanizes more rapidly than one containing only new rubber. Therefore, when reclaim is used in a compound, a corresponding reduction in the amount of accelerating agents is possible, with consequent saving in product cost. Also, the filler contained in the reclaim makes possible a proportionate reduction of filler added to the batch.

A compound in which reclaim is present is easier to mix than one containing only new rubber, resulting in a saving of time and power and in lower final costs.

Reclaim improves extruding properties of compounds used for making tubing, gasket strips, and other extruded shapes. Some extruded products contain no new rubber, reclaim alone (plus necessary compounding ingredients) being adequate.

Reclaim in a compound improves calendering characteristics in forming sheets or coated fabrics.

Compounds used in making molded rubber goods are easier to process when they contain reclaimed rubber.

The use of all-new rubber for certain products that do not have to live up to high performance standards would represent a waste of part of the rubber, just as the use of high-speed steel for making butter knives would be a waste. By using reclaim, a proportionate part of new rubber is released for other and more important uses. For a considerable number of products, such as certain adhesives and adhesive tapes and the extrusions already mentioned, no rubber other than reclaimed is used.

By lowering production costs, either because it is itself cheaper or because it permits processing economies, reclaimed rubber may make it possible to incorporate a rubber element in a certain product when the use of all-new rubber would cause product cost to be prohibitive. Another angle is that the use of reclaimed rubber helps maintain stability of product price. In the past, the cost of other rubber has varied greatly, from 3½ cents to $1 per pound, while the cost of reclaim hovered around the 4- to 7-cent mark. Thus, wide fluctuations in new rubber cost produce less violent variations in the cost of products containing considerable percentages of reclaim than in products made of all-new rubber.

Designers sometimes are needlessly afraid of permitting reclaimed rubber to be used in their new products. In the opinion of reclaim specialists, a designer, in setting up specifications for a rubber product, should carefully consider the establishment of just what measurable properties it is important to control, based on his knowledge of actual service requirements. From then on, he can leave to the rubber manufacturer the matter of whether or not reclaim can be used in meeting the specifications.

American rubbers, as well as crude, are being reclaimed.

American-made Rubbers[1]

Ever since the usefulness of crude rubber was recognized, scientists have attempted to match nature by synthesizing it in the laboratory or factory. At first the goal was to duplicate crude rubber precisely—an aim that has not yet been achieved. Today the objective in developing a new synthetic or applying an older one is almost always to obtain a material having properties tree rubber does not possess. Actually, no one has yet made a true synthetic rubber but only rubberlike approximations of the natural product.

The rubber tree manages to string together carbon-hydrogen molecules to form large, complex molecules of the substance we call crude rubber. By distillation, this rubber has been broken down and has been found to consist mostly of isoprene, $CH_2{:}CHC(CH_3){:}CH_2$, a liquid resembling gasoline. By polymerization, chemists can rebuild the relatively simple molecules of isoprene into heavier ones forming a substance resembling the original rubber, but so far no one has been able to recreate crude rubber that way.

The process of polymerization forms the basis for the making of most American rubbers. It converts liquids or gases into rubbery materials by combining their molecules into larger, more complex molecules or chains without changing the chemical composition. A single substance may be

[1] Since the word "synthetic" means "an exact duplication of" some natural product or substance but is commonly interpreted to mean an imitation or substitute (perhaps inferior) for something else, and since no rubber made by man ever has been an exact duplication of the original kind that Nature produces, the words "American or "American-made" rubber are being increasingly used as designations for that group of rubbers formerly called "synthetic" or "man-made." Therefore, throughout this book, the term "American" or "American-made" has been employed and denotes rubbers synthesized on the American continents.

Also, the word "crude" has been used throughout to designate tree rubber and that from similar natural sources. The term "raw crude" would indicate the basic hydrocarbon as appearing in latex, etc.; "unvulcanized crude" would mean the compounded but uncured form; and "vulcanized crude" the cured form of rubber from natural sources. In a parallel sense, the terms "raw American rubber," "raw GR-S," etc., would be used in referring to synthetized types.

polymerized into American rubber, or two or more basic substances copolymerized to form an American rubber having properties superior to those obtainable from one substance alone.

The following tabulation includes American rubberlike materials that are available commercially, plus a few that though not of current com-

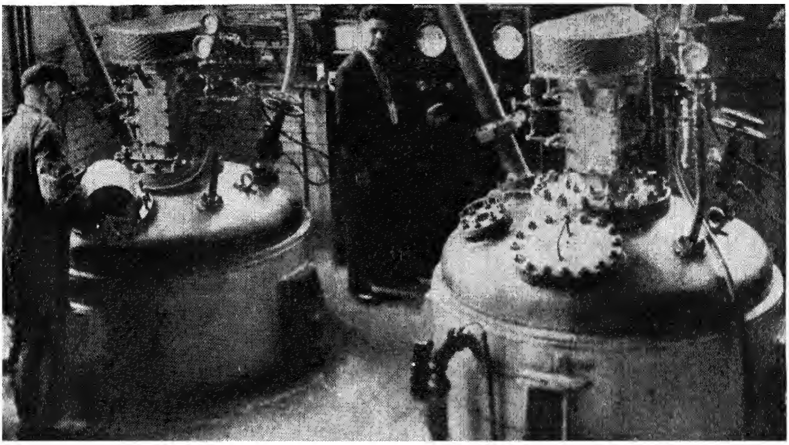

Fig. 3. In these vessels, butadiene and acrylonitrile are converted into Nitril-type American-made rubber. Each of the polymerizers produces a ton of the raw rubber at a time.

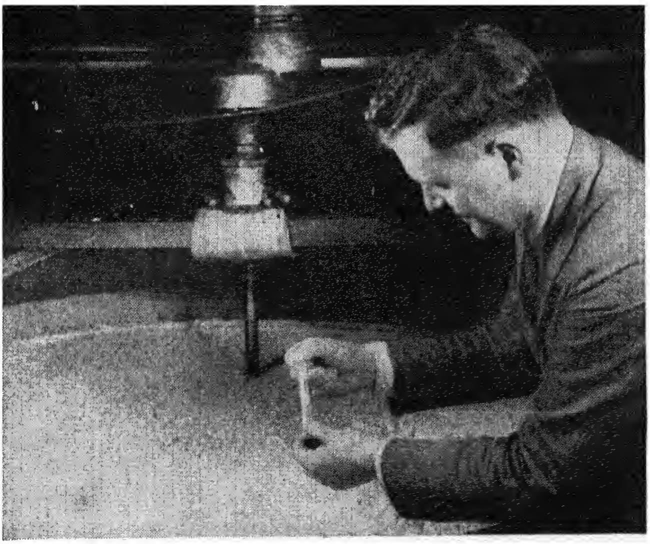

Fig. 4. Raw American-made rubber after being coagulated.

mercial importance, have been made and are of historical interest or may be extensively used someday. Further details concerning the most important American rubbers will be found in other chapters. Manufacturers' names are given adjacent to the trade names listed.

Butyl Rubber. This is an all-petroleum product made by copolymerizing isobutylene and just enough isoprene to permit vulcanization. (Butadiene may be used instead of isoprene.)

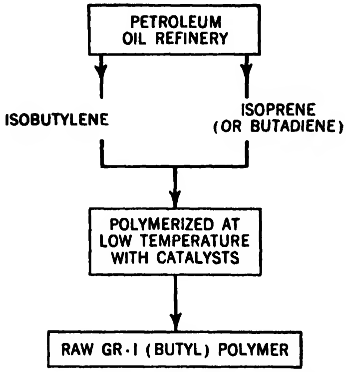

Fig. 5. Flow diagram showing how Butyl rubber is made. The end product is the raw, uncompounded form.

Butyl rubber shows excellent resistance to vegetable oils, lard, and oleic acid. Its high resistance to gas permeation accounts for many of its applications, including the making of inner tubes.

Trade names include Butyl Rubber, Flexon (Standard Oil Company of New Jersey, New York). Its war-emergency designation was GR-I. (Flexon has been discontinued.)

Cyclized Rubbers. Rubber that has been changed into isomeric materials and deprived of some or all of its rubbery characteristics is known as cyclized. It is used for coating paper and making adhesives, films, and paints, and it is compounded with other forms of rubber to make material for shoe soles, coatings for cables, etc.

Trade names include Thermoprene, Vulcalock cement (The B. F. Goodrich Company, Akron, Ohio); Pliolite resins (The Goodyear Tire & Rubber Company, Akron, Ohio); Marbon B (Marbon Corporation Gary, Ind.).

GR-S Type and Other Butadiene-styrene Rubbers. These are made by copolymerizing butadiene and styrene.

This is the type of American-made rubber used most extensively in tires. During the Second World War, about 85 per cent of the American rubber produced in the United States was of this classification. It most nearly resembles crude rubber, both in processing and performance characteristics. GR-S is not resistant to oils.

Trade names of American rubbers in this family include Ameripol F (The B. F. Goodrich Company, Akron, Ohio); Chemigum B (Goodyear Tire & Rubber Company, Akron, Ohio), Butaprene (Firestone Tire & Rubber Company, Akron, Ohio); Hycar OS-10 and OS-20 (The B. F. Goodrich Chemical Company, Cleveland, Ohio); and Nubun (U.S. Rubber Company, New York). The designation "GR-S" means "Government Rubber-Styrene" and refers to the American rubber made during

the Second World War in United States government-owned plants. Buna S, a German term, is a trade name for a rubber synthesized from similar raw materials, but it is not the same as American-made GR-S.

Methyl Rubber. This was brought out independently in this country and by the Germans around 1912, was tried in tires and a few other products in the First World War, and then apparently was relegated to history. Methyl H and Methyl W rubbers were produced from dimethyl butadiene.

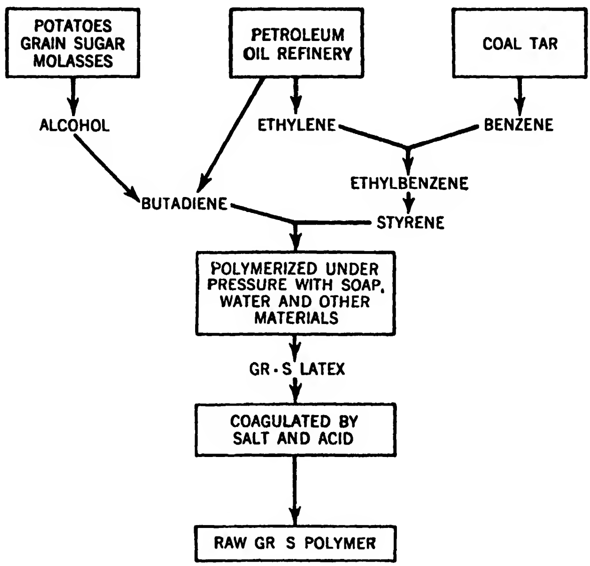

Fig. 6. Flow diagram for GR-S.

Neoprene. Neoprenes are made by polymerizing chloroprene (chlorobutadiene). Excellent resistance to ozone; good resistance to oils, sunlight, heat, and aging; and good mechanical properties are features of this family. The Neoprenes are used for oil hose, gaskets, belts, wire insulation, vibration insulators, and other applications where oil is likely to be encountered.

Trade names include Neoprene Types E, M, GN, FR, CG, and KN (E. I. Du Pont de Nemours & Company, Inc., Wilmington, Del.). War-emergency designation was GR-M.

Nitril Rubber. A type of American rubber made by copolymerizing butadiene and acrylonitrile. The outstanding characteristic of Nitril rubber is its resistance to oils and other solvents. It also has excellent abrasion and age resistance. Products in which it is used include oil, fuel, and solvent hose; hydraulic equipment parts; sheeting; etc.

Trade names include Ameripol D (The B. F. Goodrich Company, Akron, Ohio); Butaprene N (Firestone Tire & Rubber Company, Akron, Ohio); Chemigum N-1, N-2, and N-3 (The Goodyear Tire & Rubber

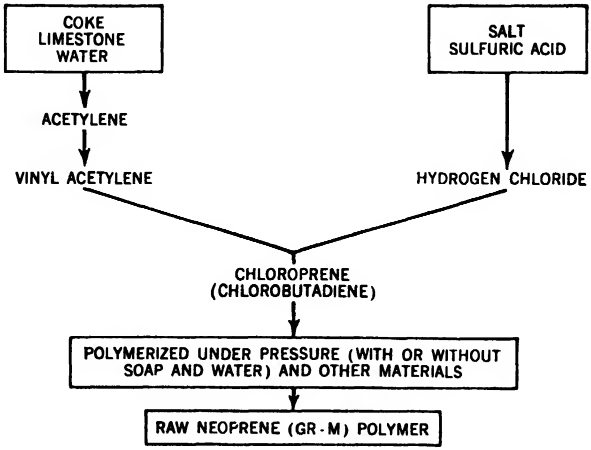

FIG. 7. Flow diagram for Neoprene.

Company, Akron, Ohio); Hycar OR-15 and OR-25 (B. F. Goodrich Chemical Company, Cleveland, Ohio); Perbunan (Standard Oil Company of New Jersey, New York). Buna N is a German rubber made from similar

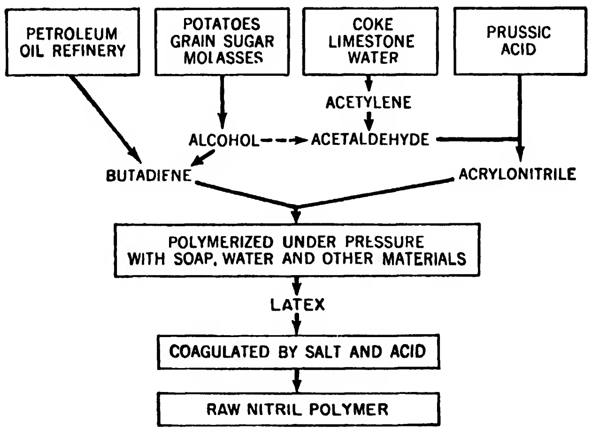

FIG. 8. Flow diagram for Nitril rubber.

materials and having similar properties, but it is not identical with American-made Nitril rubber. War-emergency designation was GR-A.

NOREPOL OR "SOYBEAN RUBBER." American-made elastic materials having rubberlike properties have been made by polymerizing fatty acids

derived from agricultural products such as soybean oil. They are used for making gaskets, fruit-jar rings, tubing, etc.

Trade names include Agripol (Reichhold Chemicals, Inc., Detroit, Mich.); Norepol (Northern Regional Research Laboratory, U.S. Department of Agriculture, Peoria, Ill.).

POLYBUTENE (POLYISOBUTYLENE OR POLYISOBUTENE) RUBBER. This is made by polymerizing isobutylene in the presence of catalysts, the result being a saturated hydrocarbon. The molecular weight of polybutene may be varied; and in this way, it can be produced as a liquid and (by increasing molecular weight) as a tacky fluid or a solid exhibiting elastic properties. Polybutene rubber cannot be vulcanized. It has high resistance to oxidizing agents and corrosive chemicals. Mixed with other types of rubber, it is used for electrical insulation in high-voltage work. Other applications include mixing it with greases and oils to improve their viscosity at extreme temperatures.

Trade names include Vistanex (Standard Oil Company of New Jersey, New York) and Oppanol, which is a German term.

POLYESTER. This is a type of elastomer made from glycols and dibasic acids or from hydroxy acids. It can be vulcanized with sulfur. Products are resistant to gasoline and oils and to dry heat and retain flexibility at low temperatures.

Trade names include Paracon (Bell Telephone Laboratories, New York) and Paraplex X-100 (Resinous Products and Chemical Company, Philadelphia, Pa.).

POLYETHYLENE. A thermoplastic polymer of ethylene, its excellent electrical properties make it useful for radio-equipment parts, cable insulation, etc. It has good chemical resistance and is little affected by moisture, and extensive temperature variations do not destroy its toughness or flexibility.

Trade name is Polythene (E. I. du Pont de Nemours & Company, Inc., Plastics Department, Arlington, N. J.); polyethylene (Bakelite Corporation, New York).

SILICONE RUBBER. The silicones are a group of plastic materials built from silicon, oxygen, hydrogen, and carbon. In the rubbery form, the plastic has poor mechanical properties but possesses extraordinary heat resistance and is therefore useful in gaskets and for other applications where elevated temperatures are encountered. Silicones are used also in electrical insulation.

Trade names include G-E silicone rubber (General Electric Company, Schenectady, N. Y.); Silastic (Dow Corning Corporation, Midland, Mich.).

STYRENE-BUTADIENE COPOLYMERS CONTAINING MORE STYRENE THAN THE GR-S TYPE RUBBERS. This family of hydrocarbon plastics can be

produced in a wide range of properties. Some are not very extensible but retain flexibility at very low temperatures. They can be incorporated into various elastic materials as reinforcing agents or to resist moisture absorption or to improve electrical properties.

Trade names include Styraloy 22, 22A, and Q-127 (Dow Chemical Company, Midland, Mich.); Hycar OS-10 and Goodnite Resin 50 (B. F. Goodrich Chemical Company, Cleveland, Ohio); Pliolite S-3 and S-6 (Goodyear Tire & Rubber Company, Akron, Ohio); Darex Copol (Dewey & Almy Company, Boston, Mass.).

SULFIDE RUBBERS. Materials in this group, sometimes called thioplasts, are made by condensation. Thiokol A results from a reaction between ethylene dichloride and sodium polysulfide, while Thiokol FA is similarly made from dichloroethyl ether and sodium polysulfide. Other varieties of Thiokols have been produced. Rubbery characteristics develop with an increase of molecular weight.

These polysulfide rubbers have good resistance to oils and solvents, including acetone and carbon tetrachloride. They withstand low temperatures, ozone, and sunlight well but have low heat resistance, and their tensile strength has not approached the maximum developed by rubber. Applications include the making of hose for oil and solvents, linings for gasoline and chemical tanks, and numerous other products used where oils, solvents, and other chemicals must be resisted. Vulcanized Thiokol rubber, being thermoplastic, can be remolded.

Trade names include Thiokol A and FA (Thiokol Corporation, Trenton, N.J.) and Wagum (American Wagum Rubber Company, Grand Prairie, Tex.).

VINYL PLASTICS. Although the various elastic vinyl plastics are not always grouped with American-made rubbers, they often overlap into the rubber field by acting as substitutes or replacements for crude rubber. Vinyl plastics are made from four common raw materials: limestone, coke, salt, and water plus various plasticizers, coloring agents, etc.

Polyvinyl Butyral. This plastic is made in a roundabout way by polymerizing vinyl acetate and then replacing part or all of the acetate by butyraldehyde. It becomes rubbery when sufficient plasticizer is added and was first used extensively as the flexible "sandwich" in shatterproof glass. During the war, it found many uses as flexible coatings on fabrics.

Polyvinyl Chloride. This is often abbreviated PVC and is made by polymerizing vinyl chloride. This resin was a laboratory curiosity for 50 years, and then a process of modifying it by the addition of plasticizers was worked out in the B. F. Goodrich Laboratories, which opened the way for the development of a considerable group of synthetic elastic resins.

Properties of plasticized PVC include resistance to sunlight, prolonged flexing, strong corrosives, and oxidation; absence of swelling or other damage in the presence of certain solvents and oils; color attractiveness; and high abrasion resistance. The plastic is used for an almost limitless variety of purposes, from coating rainwear and shower curtains to lining chemical tanks and making flexible molds. A complete description of the properties of plasticized PVC can be found in Chap. 23.

TABLE 1. PROPERTY RELATION OF CRUDE AND AMERICAN-MADE RUBBER

Property	*Comparison with Rubber*					
	Crude rubber	*Neoprene (GR-M)*	*Thiokol*	*Nitril*	*GR-S*	*Butyl (GR-I)**
Workability†	Excellent	Good	Fair	Good	Good	Good
Vulcanizing properties	Excellent	Excellent	Fair	Excellent	Excellent	Good
Adhesion to metals	Excellent	Excellent	Poor	Excellent	Excellent	Good
Adhesion to fabrics	Excellent	Excellent	Fair	Good	Good	Good
Resistance to swelling in lubricating oil	Poor	Good	Excellent	Excellent	Poor	Poor
Resistance to deterioration in oil	Poor	Excellent	Fair	Excellent	Poor	Good
Resistance to aromatic hydrocarbons (benzol, toluene, xylene, etc.)	Poor	Poor	Good	Fair	Poor	Fair
Resistance to chlorinated hydrocarbons	Poor	Poor	Good	Good	Poor	Poor
Resistance to lacquer solvents	Poor	Poor	Good	Fair	Poor	Poor
Gas diffusion	Fair	Good	Excellent	Good	Fair	Excellent
Resistance to diffusion of petroleum products	Poor	Fair	Excellent	Excellent	Poor	Poor
Adaptability for contact with food*	Excellent	Fair	Poor	Fair	Fair	Good
Dielectric strength*	Excellent	Fair	Fair	Fair	Excellent	
Electrical conductivity*	Fair	Fair‡	Fair	Fair‡	Fair	Fair
Resistance to water absorption*	Fair	Good	Fair	Good	Good	Fair
Resistance to strong oxidizing agents	Poor	Poor	Poor	Poor	Poor	Good
Resistance to other corrosives	Good	Good	Good	Good	Good	Good
Tensile strength*	Excellent	Good	Fair	Excellent	Good	Fair
Elongation	Excellent	Excellent	Fair	Excellent	Good	Excellent
Resistance to cold flow*	Excellent	Good	Poor	Excellent	Excellent	Fair
Resistance to sunlight*	Fair	Excellent	Excellent	Good	Fair	Excellent
Resistance to ozone*	Fair	Excellent	Excellent	Good	Fair	Excellent
Resistance to aging	Good	Excellent	Excellent	Excellent	Excellent	Excellent
Approx. specific gravity basic material	0.93	1.23	1.34	1.00	0.94	0.92
Heat resistance*	Good	Excellent	Poor	Excellent	Excellent	Excellent
Flame resistance	Poor	Good	Poor	Poor	Poor	Poor
Cold resistance*	Excellent	Good	Fair	Good	Excellent	Good
Rebound elasticity (snap)	Excellent	Good	Good	Fair	Good	Poor
Abrasion*	Excellent	Good	Poor	Excellent	Excellent	Fair
Tear resistance*	Excellent	Good	Poor	Good	Fair	Good
Abrasion resistance—soaked in oil	Poor	Fair	Poor	Excellent	Poor	Poor
Hardness durometer A tests (100 is bone hard)	20–100	20–90	35–80	20–100	35–100	15–190
Color range	Good	Good	Poor	Good	Good	Good
Freedom from odor*	Excellent	Fair	Poor	Fair	Good	Good
Resistance to paint and ink driers	Poor	Excellent	Excellent	Excellent	Excellent	Excellent

* These properties available only in specific compounds.

† All American rubbers can be worked on rubber machinery, but in some products they are more difficult and expensive to fabricate than crude rubber due to lack of tack.

‡ Electrically conductive compounds with more "rubbery" characteristics can be made of these synthetics than is the case with crude rubber, which has to be very heavily "loaded" to attain the same degree of conductivity.

Vinyl Chloride Copolymers. When vinyl chloride is mixed with small proportions of other polymerizable chemicals such as vinylidene chloride or vinyl acetate, copolymers are made differing somewhat from pure PVC. One of the important differences is increased solubility, which makes these copolymers especially suited for uses in which solutions are required. Thus, solution coating of fabrics with flexible vinyl plastics is preferably carried out with one of these copolymers. When fabricated into soft plasticized products, the copolymers generally require a little less plasticizer than PVC to give the same degree of softness.

Polyvinyl Alcohol. This is often abbreviated PVA and is made by hydrolyzing polyvinyl acetate. It is water-soluble but can be made water-resistant. A copolymer with vinyl acetate can be produced by partial hydrolysis of polyvinyl acetate. Polyvinyl alcohol is highly resistant to oils, gasoline, and many other materials classed as solvents.

Trade names of some representative vinyl plastics are given in the following list:

Vinyl chloride polymers and copolymers:
- Geon (B. F. Goodrich Chemical Company, Cleveland, Ohio)
- Koroseal (The B. F. Goodrich Company, Akron, Ohio)
- Marvinol (The Glenn L. Martin Company, Baltimore, Md.)
- Pliovic (Goodyear Tire & Rubber Company, Akron, Ohio)
- Ultron (Monsanto Chemical Company, Springfield, Mass.)
- Velon (Firestone Tire & Rubber Company, Akron, Ohio)
- Vinylite (Bakelite Corporation, New York)

Polyvinyl butyral:
- Butacite (E. I. duPont de Nemours & Company, Inc., Arlington, N.J.)
- Butvar (Shawinigan Products Corporation, New York)
- Saflex (Monsanto Chemical Company, Springfield, Mass.)
- Vinylite (Bakelite Corporation, New York)

Polyvinyl alcohol:
- DuPont PVA (E. I. duPont de Nemours & Company, Inc., Wilmington, Del.)
- Resistoflex compar (Resistoflex Corporation, Belleville, N.J.)

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Chapter 2

PROPERTIES OF RUBBER

"I handled more rubber last week than I did all of last month," a rubber-plantation worker remarks.

"They certainly put a lot of rubber parts on my new car," a motorist observes.

Both of these men are talking about "rubber," but are they discussing the same thing? Not exactly. One refers to a basic raw material; the other to a group of finished products. As mentioned in Chap. 1, the term "rubber" as usually employed means, not a single material, but a thousand and more compounds, each possessing a different set of properties. Formerly the term implied that natural rubber was the base material, but now a new complication has been added, and the word "rubber" might indicate that any one of a variety of synthetic materials has been used.

Because of the virtually infinite number of compounds that manufacturers might make, it has not been feasible for the rubber industry to supply data on them in handbook form, as has been done with many other industrial materials. The chemical and physical properties of commercially used rubber compounds vary so widely that it is difficult to give specific values for each of the important properties without these values being so all-inclusive that they lose significance. In this chapter, however, some of the more important properties of rubber materials will be described, and the range of values normally encountered by processors and users of rubber will be indicated. Brief descriptions of some of the test methods commonly used for measuring those properties are included.

In the following discussion, the term "rubber" will be used to denote any composition of crude or American-made rubber except hard-rubber compounds; these hard compounds consist of mixtures vulcanized to the bone-hard state or nearly so by the use of a high percentage of sulfur and prolonged heating. All other rubber compounds are generally classified as "soft," even though some of them may be made virtually as hard as true hard rubber by the addition of fillers. (Properties of hard rubber are given in Chap. 11.)

Adhesive Properties

A frequently used property of unvulcanized rubbers is their stickiness or adhesive ability. Unvulcanized crude rubber, in particular, possesses the important property of "tack." This is defined as that property which causes two layers of stock that have been pressed together to adhere so firmly that when pulled apart, they will separate at some point other than at the original two surfaces. Further discussion of the tackiness of rubber will be found in Chap. 3, on Adhesives.

Vulcanized Rubber

By far the most important uses for rubber are those requiring (1) the compounding of the basic hydrocarbon with various vulcanizing agents, softeners, reinforcing agents, fillers, and other materials, and (2) the subsequent vulcanization or curing of this mixture into a more or less homogenous mass. Vulcanization, key to most rubber manufacturing, is most commonly accomplished by the application of heat, which results in a chemical reaction.

Changes brought about by the vulcanization process are indicated in the following diagram:

Unvulcanized		*Vulcanized*
Low strength Low recovery when stretched and released High plasticity High solubility in solvents High freezing point Low softening point	Vulcanization $\longrightarrow$	High strength High recovery when stretched and released Low plasticity Insolubility in solvents Low freezing point High softening point

Stress-strain Properties, Elasticity and Resilience

A unique and most important property of vulcanized rubber is its ability to recover almost completely after extreme distortion by tension, compression, or shear. Other materials may have greater elasticity and resilience, but their range of elasticity is limited to small deformations of the order of 10 per cent or less, while pure gum rubber may be stretched more than 600 per cent and then will return to within a few per cent of its original length when the tension is released. Although rubber is less strong than steel, its ability to recover after extremely high deformation permits it to store much greater energy than any other material. Table 1, prepared by Weigand, compares several materials in respect to capacity for storing energy.

TABLE 1. ENERGY-STORING ABILITY

Material	*Energy, Ft-Lb/Lb*
Gray cast iron	0.37
Extra soft steel	3.07
Phosphor bronze	4.08
Rolled aluminum	7.56
Hardened and tempered spring steel	95.30
Hickory wood	122.50
Vulcanized rubber	14,600.00

Measurements of the relation between load and stretch or load and compression and of the degree or efficiency of recovery of the specimen after distortion are the most important and frequent tests used in the rubber industry. By far the most widely used of these is the stress-strain

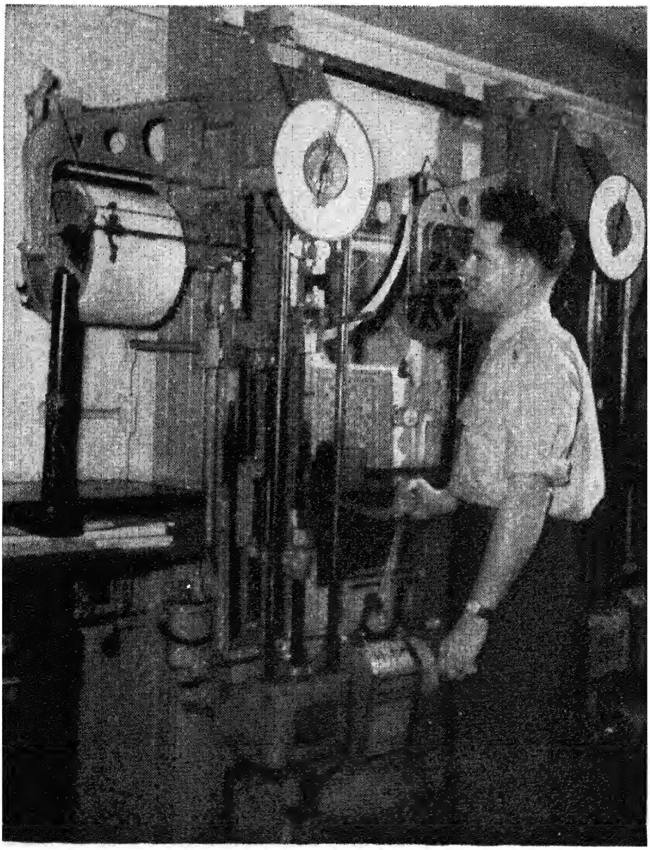

FIG. 1. Determining tensile strength and elongation of a test specimen of rubber with a Scott testing machine.

test or, if the intermediate values of stress and strain prior to the breaking point are not desired, the tensile and elongation test.

TENSILE AND ELONGATION (STRESS-STRAIN) TEST

The test is run by stretching a dumbbell-shaped specimen ⅛ inch or less in thickness at the rate of 20 inches per minute. This is done by a motor-driven machine having two clamps between which the specimen is held. One of the clamps is attached to a weighing mechanism, which is usually a weighted pendulum and scale arrangement, while the other clamp, which is moved by the motor, does the stretching. Two reference lines usually 1 inch apart are stamped with ink on the narrow, restricted "handle" portion of the dumbbell. As the sample is stretched, the operator observes the position of the reference lines and, at each 100 per cent increase in the distance between them, records the load as indicated by the weighing device. Stretching is continued until the sample breaks. The load and amount of stretch at break are referred to respectively as the ultimate tensile strength and the ultimate elongation. The tensile strength is calculated with respect to the original cross-sectional area of the specimen, and not on the area at the time the specimen breaks, because the actual area at break would be extremely difficult to determine. In calculating the tensile characteristics of metals and most other materials, the actual cross-sectional area at time of break is used. This difference should be kept in mind when comparing rubber with, say, steel.

The actual breaking of a test dumbbell occurs suddenly and exhibits the characteristics of an accident. Years of rubber testing and research have provided no positive assurance that the failure occurs at the maximum stress that the rubber could withstand. In most cases, the ultimate break is probably a tear started by some imperfection in the specimen. Because of the considerable quantity of energy stored in the rubber, the tear progresses so rapidly that it appears to be instantaneous.

A typical stress-strain curve obtained in the way just described is shown in Fig. 2.

The curve does not follow Hooke's law (which states that stress is proportional to strain up to the elastic limit) except up to the very low load of 50 psi. The value of tensile stress existing at an intermediate degree of elongation before the breaking elongation is reached is referred to as the "modulus." (This is not to be confused with the modulus of elasticity.) When the modulus of rubber is referred to, the percentage of elongation must always be stated. Thus a modulus of 850 psi at 600 per cent means that a pull of 850 psi is required to move the reference marks from 1 to 7 inches apart, *i.e.*, to produce an elongation of 600 per cent.

Various rubbers differ widely in their tensile and elongation properties and in the influence of compounding variables on these properties. For example, the type of compound used for natural-rubber bands consists only of rubber and vulcanizing agents and is known as a "gum" or "pure gum" stock. When made from GR-S, Thiokol, or Nitril rubbers, these

pure gum compounds have very poor properties. However, when they are reinforced with certain carbon blacks, good properties can be obtained. Both tensile strength and elongation are affected by the temperature at

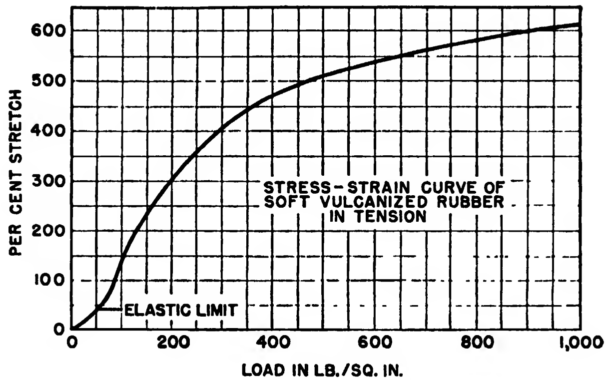

FIG. 2. A study of this stress-strain curve discloses that rubber does not behave according to Hooke's law except at very low elongations. Stress is proportional to strain up to about 50 psi. Within this limit, high-grade soft vulcanized rubber will be almost perfectly elastic under repeated reversals of stress.

which they are determined, and changes in temperature and therefore in these properties frequently have a pronounced effect on the service performance of products.

TABLE 2

Material	*Gum stocks at room temp.*		*Carbon-black stocks at room temp.*		*Per cent of RT properties retained at 210°F**	
	Tensile psi	*Elong. %*	*Tensile psi*	*Elong. %*	*Tensile psi*	*Elong. %*
Crude rubber......	2,500–3,500	750–850	3,500–4,500	550–650	65	110
GR-S............	200–300	400–600	2,500–3,500	500–600	33	55
Neoprene (GR-M).	3,000–4,000	800–900	3,000–3,500	500–600	40	70
Butyl (GR-I).......	2,500–3,000	750–950	2,500–3,000	650–850	40	120
Nitril, Hycar OR-15..	600–900	500–700	4,000–4,500	500–650	25	65
Thiokol FA........	100–200	450–550	1,500–1,700	600–700	33	65

* RT = average room temperature = 70°F.

In Table 2, data taken from Ball and Maassen, published in the ASTM Symposium on Application of Synthetic Rubber, are shown, comparing the tensile and elongation properties of various rubbers in

pure gum and in carbon-black stocks. Effect of higher test temperatures on the carbon black stocks is also shown.

Stress-strain tests are also run in compression, as contrasted to tension. However, such compression tests are seldom run to failure, the objective being to determine the stiffness or softness of the rubber compound under compressive loads. The results obtained vary widely, depending on the size and shape of the test specimen and the condition of the metal surfaces in contact with the specimen. In Fig. 3 is shown a combined tension and compression curve for a pure gum rubber with the unit stresses calculated on both the initial cross section and the actual cross section.

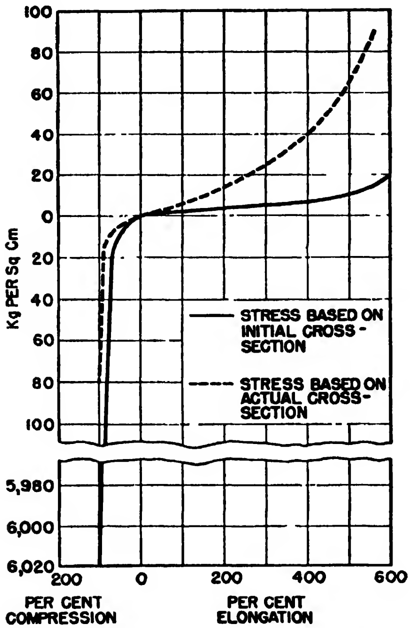

FIG. 3. Tension-compression curves for crude-rubber (pure-gum stock).

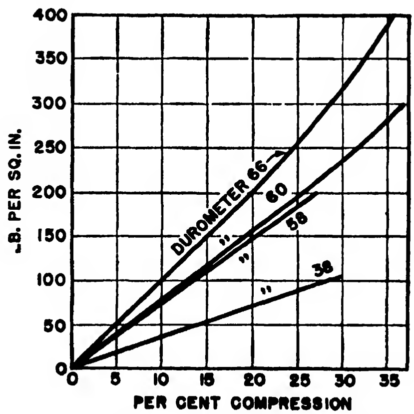

FIG. 4. Behavior of 1-inch rubber cubes under compression loading.

In Fig. 4, compression loading curves for 1-inch cubes of varying hardness are shown.

It will be noted that these curves are straight up to 20 per cent compression. This has been found true for all shapes in which the ratio of thickness to effective width is 1 or less. This is also the deflection range in which rubber compression (shock- or vibration-absorbing) devices are recommended for use. The precise position of the load-deflection curve depends (in addition to the rubber hardness) on the cross-sectional area, the above ratio of thickness to effective width, and the degree of slippage between the rubber and the loading plates.

The moduli of elasticity in shear, tension, and compression (no slippage) for stocks of different durometer[1] hardnesses are shown in Table 3.

[1] See p. 26.

The tension modulus is equal to the compression modulus when lubrication is used between the specimen and the compression loading plates.

For determining the degree to which a rubber composition fails to be elastic, a variety of tests are used and include rebound tests, permanent-set tests, and hysteresis measurements.

TABLE 3. MODULI OF ELASTICITY

Durometer hardness	*Shear modulus, psi/in*	*Tension modulus, psi/in.*	*Compression modulus, psi/in. (no slipping)*
40	60	180	390
50	90	270	555
60	125	375	815
70	170	510	1,105

If a stress-strain test as already described (page 19) is run to some value short of the breaking elongation and the load is recorded during both the extension and retraction parts of the cycle, a hysteresis loop is

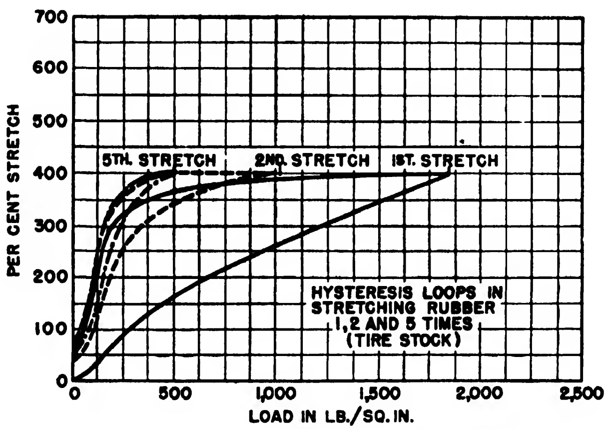

FIG. 5. With constantly repeated cycles and a constant vibrating force, the hysteresis loop areas become almost constant. But for a vibrating force of varying magnitude, the loop areas vary and afford a source of variable friction, which is desirable in some instances. Areas of loops may be varied within wide limits by varying the compound of rubber used. Highly pigmented stocks have large hysteresis losses, while pure gum types have relatively small losses.

generated, as shown in Fig. 5. The area between the extension and retraction curves is a measure of the energy lost during the cycle. This loss is greatest for the first cycle, decreasing rapidly in succeeding ones, as Fig. 5 shows. This is one way of measuring elasticity or resilience, but this procedure is used but little at present because it is a relatively

slow test, because the elongations used are generally much higher than those encountered in service, and because the rate of reversals is much too low to give results comparable to those obtained in service.

Numerous other methods of measuring the hysteresis loss have been devised and are being used in the rubber industry. These are of two

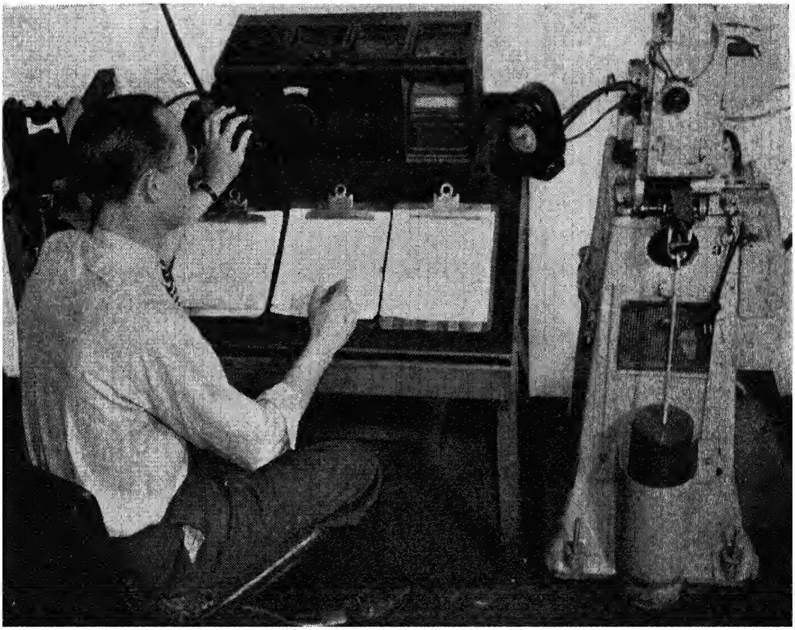

FIG. 6. This machine is a Flexometer used in determining temperature rise and permanent set induced in a rubber specimen by vibration. It can impose upon the specimen a load of 285 psi at 1,800 cycles per minute.

general types: (1) the free-vibration type, in which the rate of damping (caused by the hysteresis loss) of a vibrating sample is determined; (2) the forced-vibration type, in which a sample of rubber compound is vibrated under a fixed set of conditions and the hysteresis loss measured by determining the energy lost in the process.

THE B. F. GOODRICH FLEXOMETER

The B. F. Goodrich Flexometer is an instrument of the second (forced-vibration) type. It employs a weighted, high-inertia lever system to precompress the sample. Then it imposes upon the specimen a vibration consisting of further cycles of compression and release at the rate of 1,800 times per minute. By means of a thermocouple placed at the base of the cylindrical specimen, the temperature rise of the specimen is measured.

Table 4 gives the relative ratings of the various American-made rubbers with respect to crude rubber, based on heat rise in a forced-vibration test, as reported by Ball and Maassen in the ASTM Symposium on Application of Synthetic Rubber.

TABLE 4. RELATIVE RESILIENCE

Material	*Percentage Rating*
Crude rubber ..	100
GR-S	75
Neoprene (GR-M) . .	90
Butyl (GR-I)... .	60
Nitril, Hycar OR-15	75
Thiokol FA	70

The results given in Table 4 were obtained in tests on tire-tread-type compounds. Such relative ratings will vary somewhat, depending on the method of compounding, but the values in the table are probably fairly representative of the inherent properties of the various rubbers with respect to this characteristic of failing to be wholly elastic.

Permanent-set tests represent another method of determining the efficiency of a compound's recovery after being distorted. They can be run either in tension or in compression.

PERMANENT-SET TESTS

The tension methods of determining permanent-set characteristics are usually based on the stretching of a dumbbell-shaped specimen, to either a fixed elongation or a fixed percentage of the breaking elongation, holding at that point for a fixed time interval (usually 10 minutes); releasing and allowing the specimen to rest for another time interval (also usually 10 minutes); then measuring the distance between the two gauge marks. The permanent set of the specimen is usually expressed as a percentage increase in the distance between the gauge marks.

Compression-set tests are run by compressing a cylindrical specimen (usually measuring ½ inch high by 1 square inch in area) either under a constant load or at a definite, fixed deflection. After the specimen has been compressed, it may be subjected to an elevated temperature for a fixed time (usually 22 hours at 70°C).[1] Then the load is released; and after a 30-minute rest, the permanent change in the height of the specimen is measured and the per cent set calculated.

INTERPRETING PERMANENT-SET TESTS

Great care must be exercised in making comparisons among different materials by means of permanent-set tests. For example, if two materials, one soft and the other hard, are being compared as to compression set, the difference in hardness must be taken into account. In a constant-load test, the softer stock will be at a disadvantage in comparison with the

[1] 158°F.

harder stock because the softer stock will be compressed to a greater extent. But in a constant-deflection test, the harder stock will be at a disadvantage because, in deflecting it at constant value, it will be stressed to a higher value.

Table 5 shows results of compression-set tests on the principal rubbers, as determined by both methods on typical industrial product compounds.

TABLE 5. COMPRESSION-SET CHARACTERISTICS

22 hr at	*40% deflection*			*400 psi*		
	Room temp.	*158°F*	*200°F*	*Room temp*	*158°F*	*200°F*
Crude rubber.	5.0	39 0	71 0	1 5	10 0	30 7
GR-S	6 4	18 1	39 8	2 3	7 7	18 7
Neoprene (GR-M)..	7.5	34 2	94 5	2.4	6 8	47.4
Butyl (GR-I)...	14 3	41.2	66.6	3.4	10 0	18 7
Nitril, Hycar OR-15	7 5	36 0	73 2	2.6	12 6	30 9
Thiokol FA........	30 0	103 0	105.0	9.6	67 9	71 1

Rebound tests are also used to measure the efficiency of a compound in returning energy.

REBOUND TESTS

These tests are run in one of two ways: (1) A weight is dropped from a fixed height on a rubber sample, and the height to which it rebounds is measured. (2) The test is made with a pendulum instrument in which a weight is attached to the end of a pendulum and allowed to drop or swing from a fixed position against the rubber sample. The distance of rebound is measured. The ratio of the energy of the rebound to the energy of the fall is the resilience of the rubber under test.

Following are the relative resilience ratings of the principal American rubbers compared with crude rubber, based on rebound tests. These

TABLE 6. RESILIENCY RATING (REBOUND TESTS)

Material	*Percentage Rating at Room Temp.*
Crude rubber.. ..	100
GR-S.........	85
Neoprene (GR-M)	95
Butyl (GR-I)....	30
Nitril, Hycar OR-15	40
Thiokol FA.........	.. 95

results are from data by Ball and Maassen (published in the ASTM

Symposium on Application of Synthetic Rubber) and are based on tire-tread-type stocks.

Hardness of Rubber Compounds

Compounds of all rubbers are made in different degrees of hardness, and usually a hardness is selected that will comply best with product service requirements. Static hardness tests are the most common, although for many applications, dynamic hardness is of greater importance.

HARDNESS TESTS

Static hardness tests are determined by the degree of indentation produced by a plunger or indentor under a specified load. Various instruments are used in which both the dimensions of the indentor and the magnitude of the load vary The time interval between the application of the load and the taking of the reading also varies.

For these reasons, the hardness as determined by one instrument cannot be precisely converted into the values for another instrument.

Shore Durometer. This pocket-size device is the most widely used of hardness measuring instruments because of its small size and the speed with which measurements can be made. The type A durometer, which is the most widely used, has an indentor point in the shape of a truncated cone 0.031 inch in diameter at the tip and 0.052 inch diameter at the shank, with a taper of 35 degrees. The spring-imposed load on the indentor is 2 pounds. The specimen to be tested should be not less than 1/4 inch thick, or thinner specimens should be piled to that thickness or more. The operator merely presses the instrument against the rubber until the bearing plate (through which the indentor works) makes contact with the surface, and reads the hardness indicated by a pointer. The time at which the reading is taken is usually the instant at which the pointer shows the maximum or "instantaneous" value.

The type C durometer has a spring that imposes a 12-pound load on the indentor and is used for measuring stiff rubber stocks. The Type D durometer has a needle point and is used for measuring hard rubber.

ASTM Hardness Tester. This is a dead-weight device in which a 3-pound load is applied to an indentor having a spherical point 0.0938 inch in diameter. The degree of penetration is observed 30 seconds after the load has been applied and is reported in thousandths of an inch.

Pusey & Jones Plastometer. The Pusey & Jones Plastometer is another dead-weight instrument. It has a spherical indentor 1/8 inch in diameter (for most soft-rubber compounds) upon which is imposed a 1-kilogram load. The reading is taken 1 minute after the application of the load and is reported in hundredths of a millimeter. For very soft rubber, a 1/4-inch indentor is used.

Table 7 shows the durometer hardness ranges available for the various rubbers.

Table 7

Material	*Durometer A Hardness*
Crude rubber	20–100
GR-S	35–100
Neoprene (GR-M)	20–90
Butyl (GR-I)	15-75
Nitril, Hycar OR-15	20–100
Thiokol FA	25–80

Values of 100 durometer indicate that hard-rubber or ebonite stocks can be made from that type of rubber. The lower hardness values are available only in special applications.

As the hardness of a compound is varied, its other properties also change. In general, the maximum values for tensile strength, resilience, abrasion resistance, and tear resistance occur in stocks having hardness in the range of 50 to 70 durometer.

Age Resistance

None of the rubbers is completely stable with respect to age. Prior to the development of organic age resistors, which are now universally used, aging was a particularly annoying problem with natural rubber. During aging at normal temperatures, crude rubber oxidizes slowly, with a consequent loss of tensile strength and change in stiffness; it either hardens to a resinous state or softens to a gummy state. Small quantities of age resistors greatly inhibit this process, so that aging is of much less importance now than before the advent of such materials. However, if aging is speeded by high temperatures or higher concentrations of oxygen, crude-rubber products still show appreciable changes in properties.

AGING TESTS

The various aging tests are actually conditioning tests in which samples are subjected to deteriorating influences, after which the physical properties (tensile strength, etc.) are determined and compared with the properties of unaged samples of the same compounds. The deteriorating influences are either high temperatures or higher concentrations of oxygen, or both. The standard aging tests are as follows:

Geer circulating air oven at 70°C (158°F) (also at 90 and 100°C)
Bierer bomb: oxygen at 300 psi; temperature 70°C (158°F)
Air-pressure heat test: 80 pounds air pressure at 126.7°C (260°F)
Test-tube method: limited air, temperature 121 to 149°C (250 to 300°F)

Results obtained in accelerated aging tests do not necessarily forecast product performance or agree with actual service results. This is because of the fact that the deteriorating influences affecting the life of a product may include circumstances other than those which have been emphasized in the laboratory tests.

The American-made GR-S, the Neoprenes, and the Nitril rubbers differ from crude rubber, during aging, in that they become stiffer and their breaking elongation is reduced with little change in tensile strength. At normal temperatures, the rate of stiffness change is very slow, so that compounds of these American rubbers are considered more stable than those of crude rubber. The rate of stiffening increases rapidly with temperature rise. When such increase in stiffness is not objectionable, these American-made rubbers can be considered excellent for high-temperature service.

Butyl-rubber compounds show excellent age stability and, at normal aging temperatures, show little change in properties. At very high temperatures, Butyl compounds soften and lose tensile strength.

Heat Resistance

Selection of best materials for high-temperature service depends upon (1) the foregoing basic properties of the rubbers, (2) the degree of improvement attainable by compounding, and (3) product service requirements.

Also, when selecting a compound for heat service, it is desirable to know answers to the following:

1. What is maximum temperature the rubber will experience?
2. For what proportion of the time will maximum temperature be reached?
3. If maximum temperature is maintained for short intervals, what are the cooling facilities?
4. Is the product mounted in compression and fairly well confined (as a gasket)?
5. What mechanical function does the rubber part perform?

Generally, crude-rubber compounds are not recommended for use where the maximum temperature exceeds 200°F. There are exceptions: When mechanical requirements are not severe, they may be used up to 300°. American-made rubbers usually can be recommended for higher sustained temperatures than crude rubber and have been used up to 450°F. Where both oil and heat resistance are required, rubber choice is restricted to one of the Nitril or Neoprene rubbers. Silicone rubber, particularly resistant to heat, can be used up to very high temperatures if the mechanical requirements are not severe.

Flexing or Dynamic Fatigue

In many of its applications, rubber is subjected to alternating stresses. Examples include belts running over pulleys, tires deformed at points of contact with the road, shoe soles bent at each step, brake hose connections flexed at each road bump, and rubber used for insulating vibrations.

Numerous laboratory flexing tests have been developed, and many of these are in use to evaluate this characteristic both in the finished product and in specially prepared samples. Most tests are designed to imitate the type of action to which the product is subjected in service, but with one or more of the deteriorating influences emphasized. For

example, the temperature may be elevated or the speed and amplitude of the flexing increased in order to reduce time required for the test to be run.

Because all of the flexing test methods in use are empirical and do not measure a basic physical property, the technician must interpret with great care the results obtained from them. The chief use of such tests is for development and research investigations.

Tear, Cutting, and Abrasion Resistance

These three properties are of considerable importance in certain applications of rubber products. For example, air hose used in quarries must have covering that is not harmed by being dragged over rock, that is not easily cut by sharp stones, and that does not tear readily. However, none of these properties can be considered basic. Rather, each is a complex resultant of other basic properties such as modulus and tensile strength. For this reason, the methods used for measuring resistance to tear, cutting, and abrasion are empirical, and the results, though useful for comparative purposes, cannot be considered as absolute values or as being capable of correlation with service performance.

TEAR TESTS

The standard tear test is conducted by cutting a specimen in the shape of a crescent, cutting a nick 0.020 inch deep in the concave edge, then pulling the crescent in a standard tensile-testing machine. As the rubber is stretched, the concave side, being shorter, is subjected to a greater stress. The maximum load in pounds required to tear the specimen is recorded.

ABRASION TESTS

A great variety of abrasion tests has been developed, and nearly all of them involve the pressing of a sample against a moving abrasive track under fixed conditions of load, speed, and quality of abrasive. The volume of sample lost during a fixed testing interval or per unit of power consumed is reported. The most popular of these tests at the time of writing are those involving the DuPont Abrader and the Bureau of Standards Abrader.

On the basis of tear resistance, tire-tread-type stocks of the various rubbers line up in the following order, the best being first:

Crude rubber
Butyl (GR-I)
Neoprene (GR-M)
Nitril, Hycar OR-15
GR-S

On the basis of abrasion resistance of tire-tread-type stocks, the order is as follows:

Crude rubber, GR-S, Nitril, Hycar OR-15 } approximately equal
Neoprene (GR-M)
Butyl (GR-I)

Low-temperature Performance

It was mentioned previously that rubber compounds lose resilience at low temperatures. They also become stiffer and eventually reach a brittle state. The temperature at which this state is reached varies with different rubbers and with the way in which the rubber has been compounded. A great variety of test methods has been developed for measuring the low-temperature performance of rubbers, and these give different results depending on the exact conditions used in the test.

LOW-TEMPERATURE TEST

In one method of determining low-temperature performance, developed in the B. F. Goodrich laboratories, the modulus of elasticity (Young's modulus) is measured at 10° intervals from room temperature down to the temperature at which the compound becomes bone hard. The low-temperature performance of the compound is then depicted by a curve showing the relation of modulus to temperature.

In Table 8, similarly compounded stocks of various rubbers are compared on the basis of the temperature required for the modulus of elasticity to reach a value of 10,000 psi.

Table 8. Low-temperature Resistance

Material	*Pure gum stocks, °C*	*Tread stocks °C*	*A typical mechanical goods stock, °C*
Crude rubber...........	−50	−47	−49
GR-S............	.	−45	−45
Neoprene (GR-M)..	−39	−33	−21
Nitril, Hycar OR-15	−18	−18	−16
Nitril, Hycar OR-25	−29	−23	−30
Butyl (GR-I)...	−58	−40	−35

The rubber manufacturer can, by varying his compounding processes, vary the low-temperature performance of all rubbers over a wide range,

so that tables like Table 8 are only general guides. For instance, although the table shows Hycar OR-15 to be quite poor in low-temperature performance when compared with the other rubbers in similarly compounded stocks, this rubber is compounded differently in actual practice, when it is considerably better than the table would indicate. When a material is to be selected for low-temperature service, exact details of the requirements must be known before a satisfactory choice of rubber can be made. Rubber manufacturers, when furnished such details, usually can select materials and regulate compounding and other manufacturing steps so as to produce the results desired.

In addition to the immediate effects of low temperatures on the stiffness of vulcanizates (vulcanized rubber compounds), there is a long-time crystallization effect, which occurs with the so-called "crystallizable rubbers"—crude rubber, Neoprene, and Butyl. Compounds made from these materials, if held for an appreciable time at temperatures well above the temperature at which they stiffen on rapid cooling, will harden by slow crystallization. Because of differences in composition, the exact conditions required to produce this effect are so varied that no generalization can be made.

Light and Ozone Effects

For years it has been known that when compounded stocks of crude rubber are exposed under tension to light, cracks quickly appear and are positioned in a direction perpendicular to the line of stretch. GR-S and the Nitril rubbers behave in a similar way. For a long time, this cracking was thought to be caused by sunlight, particularly the ultraviolet region of the spectrum. More recently, it has been shown definitely that the cracking is caused by the action of ozone and that light is only indirectly responsible in that it converts a small fraction of the atmospheric oxygen to ozone. The ozone is formed in the stratosphere and reaches the earth's surface as a result of the turbulence of the atmosphere. Because of the readiness with which ozone reacts with most organic materials, particularly with wood and other types of vegetation, its concentration in the atmosphere is reduced rapidly at the earth's surface. When air having a fairly high concentration of ozone is carried by wind currents over a forested area before reaching a specified location, most of the gas will have been removed by the time the air arrives. On the other hand, high-ozone concentrations may exist as the result of direct downward air currents and in locations, such as those at high elevations or along a seacoast, where prevailing air currents have no opportunity to be deozonized.

Since ozone is generated by the "silent discharge" of high-voltage

electricity, ozone cracking also occurs when rubber under tension is used on or in the immediate neighborhood of high-voltage electrical conductors. This limits the use of rubber insulation to voltages not over about 600 and sometimes affects serviceability of other rubber products if high-voltage electrical equipment is near by.

The rubbers most affected by ozone—crude, GR-S, and Nitril—can be partly protected by suitable agents incorporated during compounding, so that in products which are stretched and exposed statically, cracking will be greatly reduced. When the products are being distorted during exposure (dynamic exposure), the protective agents are less effective. Fortunately, for such applications, the Butyl-, Neoprene-, and polysulfide-type rubbers are available; they all are very much more resistant to ozone than GR-S, crude, or Nitril rubbers.

Direct sunlight does affect compounded stocks in other ways, particularly stocks made of crude rubber. A slight retarding of cracking results because a tough, leathery layer is formed on the surface. If this continues a long time, the rubber surface develops a barklike appearance. Tension is not necessary. In heavily pigmented stocks, this process causes "chalking" of the rubber surface, which is the exposure of pigments in the compound as a result of destruction of the rubber binder. The chalking of highly pigmented garden-hose covers is a typical example. "Barking" and "chalking" effects are very much less prevalent with American-made rubbers than with crude rubber. Fading of colored rubber goods may also take place on exposure to sunlight.

LIGHT TESTS

Various methods of exposure to natural sunlight or to artificial light are used, depending on the conditions being investigated. The usual procedure is to stretch the rubber specimen 20 per cent or bend it in a loop if ozone cracking is being investigated. If staining, discoloration, or fading are being studied, the samples usually are exposed to natural or artificial light in the unstretched condition. Carbon arcs are one source of artificial light used in such tests.

Resistance to Water

Rubber is not a "waterproof" material, even though rubberized garments are usually considered so. Actually, any rubber compound is fairly permeable to water vapor, the permeability of a gum stock in this respect being about 50 times its permeability to hydrogen.

Selection of the base rubber, plus compounding modifications, permits varying of the permeability rate over a wide range. American rubbers generally are less permeable than crude; in natural rubber, some of the

retained proteins are believed to lower the water resistance. Specially prepared polymers of the GR-S type have shown excellent resistance to water permeability.

Resistance to Oils and Solvents

All the rubbers, both crude and American-made, are affected to some degree by certain oils or solvents. The extent to which the vulcanized materials will swell depends on the nature of the rubber and how it is compounded, the kind of oil or solvent, and the conditions of contact such as temperature, freedom to swell, and total or intermittent exposure.

Crude-rubber compounds are swollen to a considerable degree by hydrocarbons. When swollen, the rubber deteriorates rapidly because the stretching action makes the rubber more susceptible to oxygen attack. But in spite of this, rubber technicians found ways before the advent of American-made rubbers to compound crude rubber so that swelling and the subsequent rapid deterioration were greatly reduced.

Because of the very much better performance of oil-resisting American rubbers, crude rubber is seldom used nowadays in oil or solvent service. These American-made rubbers, unlike crude rubber, do not deteriorate progressively when swollen by a solvent. Selection of the most suitable American rubber and its compound for a particular application depends on (1) the degree of oil resistance required by the application, (2) all other requirements such as tensile strength, hardness, abrasion resistance, and high- or low-temperature performance. The rubber compounder has available such a variety of oil-resisting compounds and so many ways of combining them with other materials (including mixture with non-oil-resisting materials) that the combinations of properties he can create are almost infinite.

GR-S and Butyl rubber are not considered as being oil-resisting rubbers because they both swell extensively in petroleum fractions. However, Butyl rubber offers fair resistance to benzol and considerable resistance to animal fats and oils.

SOLVENT AND OIL TESTS

Tests to determine the effect of solvents and oils on rubber compounds are run under standard conditions. The temperature, time, volume of fluid, size of the rubber sample, etc., are rigidly controlled. Resistance of the rubber compound is usually evaluated by measuring the changes in its volume, tensile strength, and elongation resulting from the exposure to the oil or solvent.

In Table 9, data on swelling are given for a variety of similarly

compounded stocks of crude rubber and some of the more commonly used American rubbers in several common oils and solvents.

TABLE 9. OIL AND SOLVENT RESISTANCE OF RUBBERS

Solvent	Crude rubber	Hycar OR-15	Hycar OR-25	GR-S	Butyl	Neoprene	Thiokol FA
Percentage increase in volume after 2 weeks' immersion at room temperature							
Hexane....	144	0	.....	77.2	172	24	13
Ethyl alcohol	3	− 1 5	− 1 8	0	0 4	7 2	6
Carbon tetrachloride...	280	24	60	186	251	126	30
Benzol................	227	95	156	174	103	135	82
Acetone..............	16	163	143	11	4	28	15
Cyclo hexane..........	171	1 5	4	141	213	51	6
Percentage increase in volume after 2 weeks' immersion at 100°C (212°F)							
Circo light oil*.........	231	− 3 6	1	231	Disintegrates	86	−24
Quaker State oil†.....	274	−12 0	−10	109	Disintegrates	18	−21

* A highly naphthenic oil.
† A highly paraffinic oil.

ODOR OF RUBBER COMPOUNDS

It is frequently said that if a resident of Akron, Ohio, were to go to another city for a few days or a few years and then were blindfolded and brought home, his nose, by responding to the characteristic "rubber smell," would instantly tell him where he was. This was a particularly fitting supposition when nothing but natural rubber was being processed by the city's several rubber factories, for normally compounded stocks of crude rubber have a characteristic odor caused by the presence in the basic hydrocarbon of certain proteins and sugars. Furthermore, it is common practice to add materials such as pine tar during compounding, each of which imparts a distinctive odor of its own. Other ingredients such as reclaimed rubber and certain accelerators also may deserve some credit for contributing to the general aroma. However, by careful compounding and treatment during manufacture, it is possible to make rubber products that are essentially free from odor. In some cases, reodorants may be added to produce a more pleasing aroma.

ODOR OF AMERICAN-MADE RUBBER

Crude Butyl: Practically odorless. Any odor present in a Butyl product is contributed by the compounding ingredients.

GR-S: Slight, characteristic, inoffensive odor.

Nitril rubbers: Slight, characteristic, inoffensive odors.

Neoprene: Odor slightly more pronounced than that of other American rubber but seldom objectionable in finished products.

Thiokol FA: Pronounced odor.

Density

TABLE 10. DENSITIES OF RAW CRUDE AND AMERICAN-MADE RUBBERS

Material	*Density, grams/cm³*
Crude rubber	0.91
Neoprene (GR-M)	1.23
GR-S	0.93–0.94
Nitril (Hycar OR-15)	1 00
Butyl (GR-I)	0 92
Thiokol FA	1.33

Vulcanizates of the foregoing rubbers normally are heavier than the raw forms. The average specific gravity of industrial products is 1.20 which is equivalent to 23 cubic inches per pound. The range of specific gravities is as follows:

Pure gum crude rubber compound, 0.95.

X-ray sheet compound containing lead pigments, 5.00.

Sponge stocks, density, about 0.004 to 0.025 pound per cubic inch.

Thermal Expansion and Contraction

All soft- and hard-rubber compounds have a coefficient of expansion considerably higher than metals. Table 11 shows the range of values.

TABLE 11

*Material**	*Temperature range, °F*	*Thermal coefficient of linear expansion, in./in./°F*
Crude rubber (raw)	50–185	0 000124
Soft-rubber compounds	32 140	0 000110 0.00005†
Hard-rubber compounds	32–110	0 000010–0 000015
Aluminum	32–212	0 000012
Brass	32-212	0 000010
Glass	32–212	0 000005
Steel	32–212	0 000007

* Accurate figures are not available on American rubbers, but rough measurements indicate they would not differ substantially from those for crude rubber.

† Lower values apply to harder compounds; higher values to softer ones.

Specific Heat and Thermal Conductivity

In Table 12, these properties of rubber are compared with those of other materials.

Table 12

Material	*Coefficient of heat conductivity (metric units)*	*Specific heat (metric units)*
Soft rubber	0 00037-0 0005	0 48 (60–212°F)
Hard rubber (pure ebonite)	0 00035	0.33 (60–212°F)
Nitril rubber (Hycar OR-15)	....	0.47
GR-S	. . ...	0.46
GR-S tread	0 00081 at 158°F	
Crude-rubber tread	0 00068	0 38
Air....	0 000057 at 32°F 0 000072 at 212°F	0.24 (22–824°F)
Water.....	0 000136 at 77°F	1 0 (60°F)
Wood.....	. ....	0 33 (68°F)
Brass..	0 26	0 09 (60–212°F)
Asbestos	..... .	0.195 (60–212°F)
Asbestos sponge felt	0 000145	
Asbestos paper, laminated.	0 00017	
Cork...	0 00011	
Rock wool	0 000095	

Thermal properties of stocks depend on the amount and kind of compounding agents added and can be varied or controlled over a fairly wide range.

Thermal properties are important in vulcanization during manufacture as well as in many product applications. High specific heat and low thermal conductivity of rubber are often of importance in heat insulation. When a rubber product is flexed rapidly, hysteresis causes a rise in temperature at the center of the mass. Dimensions of the piece, flexing amplitude and frequency, and hysteresis characteristics and thermal properties of the compound determine the temperature attained.

Permeability by Gases

Resistance to permeability by gases is of importance in rubber compounds used for such articles as tubing. Table 13 contains data reported by Sager of the U.S. Bureau of Standards on gum stocks of the various rubbers.

TABLE 13*

Material	Permeability,† ml/cm/cm²/min at 25°C		
	Hydrogen	Helium	Carbon dioxide
Crude rubber	22 5	14 6	65
GR-S	19 8	12 1	
GR-S	16 2		
Neoprene (GR-M)	6 7	4 1	11
Butyl (GR-I)	3 3	4 1	1 1
Nitril (Hycar OR-15)	3 5	3 3	4 9
Nitril (Hycar OR-25)	4 1		
Thiokol FA	1 7	1 1	

* Values determined at pressure of 30 mm of water.

† Permeability is dependent on gas pressure and is inversely proportional to thickness of rubber material.

COLOR

The colors of raw rubbers and compounds are summarized as follows:

Raw crude rubber: Varies from yellowish white to dark brown. Origin and method of preparation influence color.

Vulcanized crude rubber: When vulcanizing agents are a minimum, varies from pale amber to dark amber. Most commercial compounds are black, because of incorporation of carbon black, which imparts the maximum degree of reinforcement to rubber and thus gives the maximum resistance to tearing and abrasion.

Other colors: Can be produced by blending pigments.

Pastel colors: Often require use of expensive dyes.

Light colors: Usually cost more than black for goods of equal quality.

Raw American rubbers: GR-S, Neoprene, and Nitril rubbers are light amber. Raw Butyl is nearly water-white.

Vulcanized American rubbers: Most commercial products are black. Same color range available as for crude rubber compounds.

Color and durability: Unlike crude rubber, which nature provides with nondiscoloring stabilizers, American-made rubbers require addition of stabilizing chemicals. Since the most economical and effective stabilizers discolor or stain in sunlight, light-colored American-rubber stocks may stain somewhat more readily than similar stocks of crude rubber unless the American rubber is especially prepared with non-discoloring stabilizers. This applies particularly to GR-S and Nitril rubbers.

It has been mentioned that nonpigmented, "pure gum" compounds

of GR-S and Nitril rubbers have poor physical properties but that good properties could be obtained by the addition of carbon black. To make light-colored compounds of equivalent quality would require reinforcing pigments that are light in color but similar in other respects to carbon black. Such pigments are not yet available commercially, and so light-colored rubber stocks are somewhat inferior in general quality to otherwise similar black stocks. This does not mean, however, that it is impossible to make light-colored products which are adequate for many services, for numerous highly satisfactory items are being manufactured from light-colored rubbers.

Compressibility

All rubber compounds are practically incompressible, and volume remains constant regardless of the distortion. The compressibility coefficient of rubber is approximately the same as that of water, and compressibility curves for soft rubbers are much like those for liquids. Sponge rubber's compressibility is a result of its containing air, the rubber compound itself being no more compressible than that in any other rubber product.

Electrical Properties

Crude and American-made rubbers are used extensively for insulating purposes (wire coverings, linemen's gloves, switchboard mattings, electronic equipment parts, etc.) in the electrical industries. Also, these same rubbers may be compounded to be moderately good conductors for static electricity and for producing heat by acting as electrical-resistance elements in circuits carrying direct currents or currents at 60-cycle or other normal frequencies.

The basic electrical properties of rubber compounds vary with the composition (and with the basic rubber used), with the temperature at which the properties are measured, and with the electrical frequency at which the measurements are made. In Table 14, values for power factor and dielectric constant over a range of temperatures and frequencies are given for a crude-rubber-sulfur compound containing approximately 2 per cent combined sulfur.

Table 14 is from data published by Donald W. Kitchin in *Industrial and Engineering Chemistry*, Vol. 24, p. 549 (1932), reprinted with permission of the American Chemical Society.

Table 14. Power Factor and Dielectric Constant
Figures represent per cent.

Frequency, kc	*30°C*		*50°C*		*75°C*		*100°C*	
	*P.F.**	*Di.C.*†	*P.F.*	*Di.C.*	*P.F.*	*Di.C.*	*P.F.*	*Di.C.*
0.600	0 272	2.82	0 370	2 79	0 612	2 73	1 030	2 68
0.960	..		0 397	2 79	0 523	2 74	0 930	2 67
2.160	0 353	2 78	0 296	2 79	0.477	2 73	0 743	2 68
13 5	0.147	2 82	0 290	2 77	0.399	2 70	0 570	2 68
30	0 298	2.84	0 296	2 83	0.346	2 73	0 557	2 71
60	0 412	2 82	0 321	2 76	0.338	2 70	0 470	2 66
100	0 488	2 83	0 356	2 76	0 355	2 74	0 687	2 66
300	0 870	2 84	0 440	2 78	0 370	2 71	0 389	2 64
600	1 200	2 82	0 516	2 78	0 369	2 73	0 378	2 66
1,000	1 710	2 78	0 650	2 74	0 450	2 70	0 352	2 61
2,000	2 030	2 78	0 849	2 76	0 518	2 70	0 238	2 63

* P.F. = power factor.
† Di.C. = dielectric constant.

The dielectric constants of gum stocks, as reported by Ball and Maassen, are given in Table 15.

Table 15

Material	*Specific Inductance Capacity, 1,000 Cycles, at Room Temp.*
Crude rubber	2 69
GR-S	2.68
Neoprene (GR-M)	6.7
Butyl (GR-I)	2.32
Nitril rubbers (GR-A)	5.58-10 9
Thiokol FA	7 1

Volume Resistivity of Similar Stocks

Material	*Resistivity, Ohm-cm*
Crude rubber	1×10^{15}
GR-S	1×10^{15}
Neoprene	1×10^{12}
Nitril (Hycar OR-15)	1×10^{9}

When relatively high conductivity is desired, as in the making of static conductive V-belts, volume resistivity can be lowered to less than 1,000 ohm-centimeters by compounding.

TABLE 16. AREA OF CIRCLES

Diam.	*Area*	*Diam.*	*Area*	*Diam.*	*Area*	*Diam.*	*Area*
1/8	0.012	53/64	0 539	2 1/16	3.341	6 5/8	34.472
9/64	0 016	27/32	0 559	2 1/8	3.547	6 3/4	35 785
5/32	0.019	55/64	0 580	2 3/16	3.758	6 7/8	37 122
11/64	0 023	7/8	0 601	2 1/4	3.976	7	38 485
3/16	0.028	57/64	0 623	2 5/16	4.200	7 1/8	39 871
13/64	0.032	29/32	0 645	2 3/8	4.430	7 1/4	41 283
7/32	0.038	59/64	0.667	2 7/16	4.666	7 3/8	42 718
15/64	0.043	15/16	0 690	2 1/2	4.909	7 1/2	44 179
1/4	0.049	61/64	0.713	2 9/16	5.157	7 5/8	45 664
17/64	0.055	31/32	0.737	2 5/8	5 412	7 3/4	47 173
9/32	0.062	63/64	0.761	2 11/16	5 673	7 7/8	48 707
19/64	0.069	1	0.785	2 3/4	5 940	8	50.266
5/16	0.077	1 1/32	0.835	2 13/16	6 213	8 1/8	51 849
21/64	0 085	1 1/16	0.887	2 7/8	6.492	8 1/4	53 456
11/32	0 093	1 3/32	0 931	2 15/16	6.777	8 3/8	55 088
23/64	0 101	1 1/8	0 994	3	7.069	8 1/2	56 745
3/8	0.110	1 5/32	1 050	3 1/8	7.670	8 5/8	58 426
25/64	0.120	1 3/16	1.108	3 1/4	8 296	8 3/4	60 132
13/32	0.130	1 7/32	1.167	3 3/8	8.946	8 7/8	61.863
27/64	0 140	1 1/4	1 227	3 1/2	9 621	9	63.617
7/16	0.150	1 9/32	1.289	3 5/8	10 321	9 1/8	65.397
29/64	0 161	1 5/16	1 353	3 3/4	11 045	9 1/4	67 201
15/32	0.173	1 11/32	1 418	3 7/8	11 793	9 3/8	69 029
31/64	0 184	1 3/8	1 485	4	12 566	9 1/2	70.882
1/2	0 196	1 13/32	1.553	4 1/8	13 364	9 5/8	72.760
33/64	0 209	1 7/16	1 623	4 1/4	14 186	9 3/4	74 662
17/32	0 222	1 15/32	1 694	4 3/8	15 033	9 7/8	76 589
35/64	0 235	1 1/2	1.767	4 1/2	15 904	10	78 54
9/16	0 249	1 17/32	1 842	4 5/8	16 800	10 1/8	80.516
37/64	0.263	1 9/16	1.917	4 3/4	17.721	10 1/4	82.516
19/32	0 277	1 19/32	1.995	4 7/8	18.666	10 3/8	84 541
39/64	0.292	1 5/8	2 074	5	19.635	10 1/2	86.590
5/8	0 307	1 21/32	2 154	5 1/8	20.629	10 5/8	88 664
41/64	0.322	1 11/16	2.237	5 1/4	21 648	10 3/4	90.763
21/32	0.338	1 23/32	2 320	5 3/8	22 691	10 7/8	92.886
43/64	0 355	1 3/4	2 405	5 1/2	23.758	11	95 033
11/16	0 371	1 25/32	2.492	5 5/8	24.851	11 1/8	97.206
45/64	0 388	1 13/16	2.580	5 3/4	25.967	11 1/4	99.402
23/32	0 406	1 27/32	2 670	5 7/8	27.109	11 3/8	101 623
47/64	0.424	1 7/8	2 761	6	28 274	11 1/2	103 869
3/4	0 442	1 29/32	2.854	6 1/8	29 465	11 5/8	106.139
49/64	0 460	1 15/16	2 948	6 1/4	30 680	11 3/4	108 434
25/32	0.479	1 31/32	3 044	6 3/8	31 919	11 7/8	110.754
51/64	0 499	2	3 142	6 1/2	33 183	12	113.098
13/16	0 518						

Summary

To say that the performance of rubber products depends on the physical and chemical properties of the rubber may be a mere statement of an obvious truth. However, the problem of determining what properties are involved in a particular application of rubber and what values for these properties will guarantee satisfactory product performance is an extremely complex one, and there is no simple, self-evident answer.

From the foregoing discussion of the properties of the various rubbers, it is apparent that almost infinite combinations of properties are possible —even more than the possible bridge or poker hands in a deck of cards. It is the rubber technologist's job to shuffle the properties of rubber compounds so they combine to meet the service requirements of the product. He does this by making use of the materials and techniques at his disposal, and not by chance dealing. His success depends not only on his ability to produce desired combinations of properties but also on his ability to analyze and summarize the service requirements of the product in terms of the laboratory tests with which he is familiar. In the case of products being made for the first time, the success of this last step depends on the completeness of the customer's description of the service conditions under which the product will be used and the requirements he desires it to meet.

But the customer need not—should not, in fact—overstep reasonable limits. Years of experience have shown that it is preferable for the customer to request a product which will perform certain specific tasks rather than to attempt to prescribe the material from which the product is to be made or to demand certain physical properties which may have little or no bearing on the performance of the product. Thus, it would be foolish to insist upon a high tensile strength in a rubber part that is to be used as a cushioning member and that never would be subjected to tensile stresses.

Because of the complex nature of the relationship between physical properties of a rubber compound and the performance of the product made from it, it it is suggested that rubber-product consumers who have neither the facilities for testing rubber goods nor trained technologists on their staffs to do the testing be wary of suggestions that they set up specifications for the rubber products they purchase. It is true that specifications for rubber products serve a valuable purpose in many cases, but when such specifications are employed by the unwary—by the consumer who does not quite understand all their implications or who has no facilities of his own for doing accurate testing—they may result in inferior product performance, higher cost, and a failure to incorporate new developments. It costs money to make a product to rigid specifications.

If the specifications are wrong, the product will not give maximum performance. And if the rubber manufacturer develops an improvement that the specification does not anticipate, that improvement cannot be applied to the product until a new specification makes provision for it.

A kind of three-plank platform might be used by the purchasers of rubber products:

1. Tell the manufacturer what the product is to do.
2. Explain the conditions under which it will be used.
3. Then let the manufacturer determine the properties, select the compound, and otherwise develop a product that will do the job in the best possible way.

Chapter 3

RUBBER ADHESIVES

Adhesives consisting mainly of crude, American-made, or reclaimed rubber suspensions, dispersions, or solutions are simplifying many an industrial assembly operation. Besides cementing similar or dissimilar materials together, they are used for coating fabrics, sealing against water and other liquids, binding, and protecting surfaces and for a number of highly specialized purposes such as the making of artificial spider webs for motion-picture sets.

JOINING MATERIALS. The primary purpose of any glue or cement, whether made of rubber or not, is to hold two surfaces together. Among the materials that can be joined to themselves or to each other with adhesives are wood, paper, cloth, rubber, various plastics, numerous metals, glass, ceramic materials, leather, and felt. (Metals most commonly cemented include steel, aluminum, magnesium, zinc, brass, and copper.) The joining of a material to itself, such as wood to wood, is still a major use for adhesives, but the cementing of dissimilar materials is growing rapidly in importance and is responsible for the development of many of the new adhesives.

NATURE OF ADHESION. In the past, the development of new adhesives has been largely a matter of trial and error, and this empirical method is still used widely. But the science of adhesion has progressed far enough to indicate that the old theory of how an adhesive works is only part of the story. It was generally agreed a long time ago that two surfaces are held together by an adhesive because of a purely mechanical bond. The adhesive was visualized as penetrating into irregularities, cracks, and pores—the innumerable tiny fingers thus formed enabling it to hold the surfaces together. Today this action is accepted as being important, but it does not explain why dense, highly polished surfaces sometimes are more securely bonded than rough or porous ones.

Studies aimed at finding explanations for the various factors affecting the actions of adhesives are centered around such matters as interatomic and intermolecular attractions and the spacing of molecules in the crystal lattices of compounds.

SURFACES. One time a Chicago manufacturer ordered from an Ohio rubber company a quantity of cement for attaching rubber to metal. First the metal was sandblasted; then the rubber cemented to it. Tests in the cementmaker's laboratory showed that a strong, entirely satisfactory bond would result. Likewise, the Chicago manufacturer, when the cement arrived, made tests and had no difficulty obtaining a good bond. But two weeks later, the cement manufacturer received a call from the Chicago man. "The cement doesn't work any more," he complained. "Same sandblasted surface, same technique, but no bond worth mentioning. We think the cement has spoiled." To prove his point, he sent back samples of the cement, the metal, and the rubber. Again the cementmaker's laboratory made a test; and surely enough, the bond failed to develop to the required strength. Then someone had an idea: Why not sandblast the metal again? This was done, and the cement worked perfectly.

This illustrates an important point that users of rubber adhesives (and other kinds, too) often overlook: For maximum joint strength, the surfaces to be joined should be cleaned thoroughly just before application of the cement. In cementing wooden parts in a factory, it was found that maximum strength developed when the surfaces, previously cleaned and smoothed, were sanded lightly with fine abrasive paper just before being joined. When cementing metal with one of the new adhesives such as Plastilock 500, Pliobond, Metlbond, and Cycleweld, the surfaces to be joined should be made clean and smooth. When cementing rubber to itself or to other materials, the rubber surface should be roughened with abrasive cloth or paper or with a metal grater. There are several benefits: Roughening the surface increases the area upon which the rubber cement can act. It removes any dirt or bit of greasy material that may be present on the surface. It eliminates any bloom that may have developed. When using rubber adhesives on any kind of surface, the presence of grease or oil will reduce the strength of the joint or prevent adhesion entirely. That is why it is customary to wash such surfaces with a solvent such as nonleaded gasoline.

Another common cause of failure in using rubber cements is high atmospheric humidity. Cementing should be done preferably in an air-conditioned room where humidity is low or only on "dry" days.

Because of their adhesive properties, unvulcanized rubbers are used in the form of strips or sheets, as solutions in benzol and similar solvents, or as suspensions in water for fastening together many different materials. Unvulcanized crude rubber is particularly noteworthy for its tack, which in rubber technology is described as that property which causes two layers of stock when pressed together to unite so firmly that when pulled apart, they will separate along a plane other than the juncture of the original two surfaces.

The rubber industry has developed an almost limitless variety of adhesives to satisfy almost every conceivable application problem. Successful use of such cements involves consideration of a number of factors; and when a prospective user has an adhesive problem, he should

FIG. 1. Manufacturing fuel containers by cementing together plies of American-made rubber. The rubber cement is applied by brushing.

supply the cement manufacturer with all available information concerning these factors, which include the following:

1. Surfaces to be joined.
2. Degree of bond desired—whether temporary or permanent.
3. Maximum service temperature.
4. Pressures and heat available for use in producing adhesion.
5. Type of forces to which cemented joint will be subjected in shear, compression, or direct pull.
6. Preferred method of applying cement: brushing, spraying, dipping, troweling.
7. Preferred drying conditions—whether at room temperature or with application of heat, whether at high or low humidity, drying periods permissible, etc.

CLASSIFICATIONS OF CEMENTS

Rubber cements may be classified in several ways, as in the following list:

1. Solvent-cut-back cements: Milled and compounded rubber stock treated with a suitable solvent (such as gasoline) for a period of time. Characteristics: quick drying, often inflammable. Solvent may be toxic, *e.g.,* benzol.

2. Dispersions: Reclaimed rubber dispersed in water. Characteristics: nonexplosive, noninflammable, nontoxic, special drying facilities usually

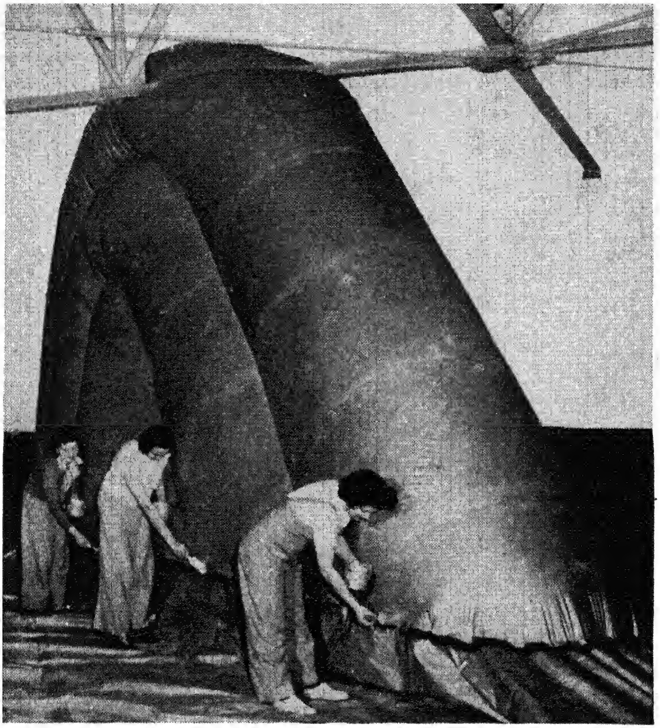

FIG. 2. Applying air-curing cement by brush to secure fabric-to-fabric adhesion. Such cement requires no heat for vulcanization, although it cures more rapidly at higher than room temperature.

required. Applications: upholstery cements and numerous other fabric cementing, nonslip rug backing, tire cord treatment.

3. Latex adhesives: Rubber latex is itself an excellent adhesive. Resins and other ingredients may be added to modify it. Latex cements are particularly effective on leather. Rings of latex cement applied to fruit-jar and similar lids form, upon drying, effective unvulcanized rubber seals, *e.g.,* Kerr-type lids.

4. Coatings: Tacky adhesive compound spread on fabric, plastic, or other material, *e.g.,* adhesive tape, Scotch tape.

Adhesives are classified according to manipulation as follows:

1. Nonvulcanizing cement: After application, develops strength by evaporation of solvent. No chemical change. Adhesion is produced by rubber that remains unvulcanized. Though weaker than vulcanizing types, the nonvulcanizing cements are adequate for many purposes and form the majority of all rubber adhesives.

2. Vulcanizing cements: There are two varieties: (*a*) heat-vulcanizing cements which, after evaporation of solvent, must be vulcanized by application of heat above room temperature; (*b*) air-vulcanizing ("room-temperature") cements, which cure slowly (several days) by exposure to air at normal room temperatures. In both cases, there is a chemical change in the rubber compound. Bonds are generally stronger than those produced by nonvulcanizing adhesives, and they resist higher temperatures.

3. Thermoplastic cements: Bond is formed by evaporation of solvent or by heating to soften cement in absence of solvent. There is no chemical change as in vulcanizing. Bond may be destroyed by later application of heat and then reformed. Many thermoplastic cements seldom maintain a bond at temperatures above 180°F.

4. Thermosetting cements: Heat must be applied to develop the bond, but further or later heating will not cause bond to loosen. Bond formation is a chemical change but is not a vulcanizing action (which would involve sulfur).

5. Pressure-sensitive adhesives: Permanently tacky surface is a characteristic, *e.g.*, adhesive surface of Scotch tape, medical adhesive tape, painter's masking tape.

The following list gives the classification with respect to the type of rubber used as base:

1. Raw crude
2. Reclaimed crude
3. GR-S
4. Neoprene (GN, CG, KN)
5. Nitril
6. Butyl
7. Thiokol

American-made Rubber Adhesives Compared with Other Types

As a rule, cements made from crude rubber cannot be used to cement American-rubber compounds. However, cements made from American rubbers are satisfactory for American and some crude-rubber compounds, and they can be used for a great many other materials such as wood,

paper, cloth, and metals. Reclaim cements are often satisfactory enough for bonding American-made rubbers to themselves and each other and to wood, metal, and fabric.

American-rubber cements are more costly than those made from raw crude rubber, largely because of the greater cost of solvents. The gasoline and other petroleum-derived solvents used in crude-rubber cements are inexpensive, but solvents required for such cements as those involving Neoprene cost several times as much. Although it generally is preferable to use the best quality cements for a particular job, some holding power must often be sacrificed in order to keep cement costs from being prohibitive. Also, for some types of adhesion, a cement that produces only moderate holding power will do as well as one producing a much stronger bond.

TACKINESS AND STRENGTH. The tackiness of a rubber adhesive is not an indication of its strength. Some of the strongest cements dry until they exhibit no tack before the joint is assembled. Other cements remain permanently tacky, yet they never develop a strong bond as compared with the most powerful adhesives.

THINNERS AND SOLVENTS. Some of the solvents used in cements are poisonous when breathed in appreciable quantity or when allowed to come into contact with the skin. One such solvent is benzol, used widely at one time in natural-rubber cements. It is a good policy to use any kind of rubber cement only in a room where there is good ventilation and to keep it off the skin as much as possible.

For most applications, cements are thinned until the solid content is 15 to 20 per cent of the total volume. The exact viscosity and percentage of solvents are determined largely by the method of application, whether by brushing, dipping, or spraying. When thinning is required, the following solvents may be used:

TABLE 1 THINNERS FOR RUBBER CEMENTS

Type of Cement Base	*Thinner*
Crude rubber	Nonleaded gasoline
GR-S	Nonleaded gasoline
Reclaim	Nonleaded gasoline
Butyl	Nonleaded gasoline
Neoprene	Isopropyl acetate
Nitril	Methyl-ethylketone

MATERIALS THAT CAN BE CEMENTED

A complete list of the materials that can be bonded, coated, or sealed with rubber cements and their near relatives would cover many pages. However, Table 2 will give some indication of the more common appli-

cations. The recommendations have proved to be satisfactory in many cases, but almost any cementing job is a problem in itself. That is, a very light bond may be needed in one instance, a very strong one in another; the adhesive may be applied by brushing in one case, by spraying in another; etc.

Trade names or numbers mentioned are those of B. F. Goodrich products, but similar cements are available from other manufacturers.

TABLE 2. TYPICAL MATERIALS THAT CAN BE CEMENTED

Materials Joined	*Type of Cement*
Canvas to rubber	Reclaim base, such as Plastikon 169
Ceramics to Formica	Plastilock 500
Cold patching (belting cover etc.)	Pure gum or American-rubber cement to match kind of compound patched
Concrete to rubber	Vulcalock
Crack filling	Rubber putty
Crash pads, airplane, etc	Reclaim base, such as Plastikon 169
Fabrics, Neoprene coated	All-purpose Neoprene cement. To make it air-curing, an activator is added
Fabrics, crude-rubber coated	Various air-curing cements
Formica to Formica	Plastilock 500
Glass to glass, ceramics, Formica, metal, wood, and plastics	Plastilock 500
Glass to paper	Vulcalock G, nonvulcanizing crude-rubber-base cement such as S-14-H
Glass to window sash (glazing)	Rubber putty
Hot patching (belt covers, etc.)	Single or combination hot-vulcanizing cement
Hycar-OR to Hycar-OR (Nitril rubber)	Nitril-base cement such as A-178-B
Hycar-OR to Neoprene	Neoprene (GR-M) base cement. Used with activator when air curing is desired (A-75-B plus A-53-C)
Leather to leather	Nonvulcanizing reclaim or American-rubber "upholstery" or "shoe-repair" cements
Leather to metal	Vulcalock or reclaim base cement
Leather to rubber	Same as leather to leather
Matting, rubber	Reclaim cements such as Plastikon 161 and 169
Metal to glass, ceramics, Formica, plastics, other metal	Plastilock 500
Metal to rubber	Numerous combinations are available for different types of metal and rubber. Consult cement manufacturer. Vulcalock is suitable for joining crude rubber to various metals, particularly steel
Metal to sponge rubber	Vulcalock or reclaim cement such as R-575-T
Metal to wood	Reclaim-base cement such as R-575-T
Neoprene to Neoprene	Neoprene-base cement, with activator if air curing is desired
Paper to paper	American-rubber or crude stationer's cement
Plastic to paper	Special American-rubber cement such as A-193-B

TABLE 2. TYPICAL MATERIALS THAT CAN BE CEMENTED.—(*Continued*).

Materials Joined	*Type of Cement*
Rubber to rubber	Because of great variety of rubber compositions used, no specific recommendations can be made. Consult cement manufacturer
Static-electricity conductive coating, as on rubber belting.	Special electrical conductive coating such as A-56-B
Upholstery	Various American-rubber-base cements such as A-193-B or reclaim base such as R-575-T
Vinyl chloride plastic to itself and to other materials	Nitril cement such as A-178-B
Wood to Formica, plastics, ceramics, glass	Plastilock 500
Wood to rubber.	Reclaim cement such as Plastikon 169
Wood to wood	Plastilock 500 or reclaim base such as Plastikon 169

TYPES OF CEMENTS

Because of constant research and the development of new preparations to meet new problems, the field of rubber and related adhesives is changing perhaps more rapidly than that of any other industrial rubber product. Adhesive manufacturers have at their command a considerable array of materials and often can solve a customer's problem by judicious use of existing preparations. When the solution is not quite so simple as that, they are prepared to develop entirely new preparations once they know all the factors involved.

Difficulties caused by a shortage of crude rubber have been reflected in the adhesive picture. It became necessary to develop cements made of American rubbers and nonrubber materials to replace crude-rubber cements for all except essential uses. In some cases, the new adhesives proved superior to those for which they substituted. In some portions of this chapter, reference is made to adhesives, *e.g.*, Vulcalock, that, because of a shortage of crude rubber, were highly restricted or temporarily suspended altogether. Some of the adhesives mentioned may not be available at all times. Also some of the American-rubber adhesives included may be replaced eventually by preparations based on crude rubber.

The following tabulation of cements is, therefore, subject to possible fluctuations in the rubber supply. It is not intended to be exhaustive, but only to provide a general picture of the adhesive field.

Table 3 is based on adhesives manufactured by the B. F. Goodrich Company; and for the purpose of providing definite means of reference, the catalogue designations are given. However, there are numerous other makers of rubber and rubberlike cements, and a number of the preparations listed have counterparts known by various other names.

TABLE 3. RUBBER AND SIMILAR ADHESIVES

Grade Designation	*Kind of Cement, Principal Uses, Etc.*
Plastikon 161	Reclaim base. Gray-black. Heavy body, requiring putty knife or other bladed applicator. Use: Bonding rubber flooring, linoleum, etc.
Plastikon 169	Reclaim base. Gray-black. High total solids but good brushing quality. Remains tacky indefinitely. Use: Cementing steel, natural rubber, GR-S, wood, reclaimed rubber, linoleum
Plastilock 315	Synthetic base. Use: Metal priming cement for attaching uncured Nitril and Neoprene to metal; attaching cured rubber and plastics to metal with aid of step-off cement
Plastilock 500 (see page 55)	Synthetic base. Use: Cementing virtually any rigid surface. For maximum strength, requires heat of 250 to 350°F. Thermosetting
Pliobond, Metlbond, Cycle Weld, Reanite (not B. F. Goodrich products)	Applications similar to Plastilock 500
No. 4	Pure gum (crude rubber) cement. High quality, good brushing properties. All-purpose cement of countless uses
60 and 61	Two-part, hot-vulcanizing pure gum. Mixed in equal portions just before use. Vulcanizing time 20 minutes at 260°F
A-53-B	Activator for making Neoprene (GR-M) adhesives air-curing
A-56-B	Neoprene (GR-M). Black. Static-conductive. Used as coating on belts, etc.
A-68-B	Neoprene (GR-M). Black. Air-drying. Use: all-purpose for joining Neoprene to Neoprene. Addition of A-53-B makes it air-curing
A-166-B	Reclaim. Light gray. Very tacky. Nonstaining. This is a memorial-stone filler cement
A-178-B	Nitril base. Tan. Translucent. Use: Bonding Koroseal material or Nitril rubber to metal, leather, fabrics
A-193-B	Butyl. Use: Laminating paper to metal foil
A-196-B	Butyl. Stationer's cement. Use: Paper-to-paper cementing in offices, etc.
A-232-B	Neoprene (GR-M). Tan color. Use: All-purpose fastening of Neoprene and GR-S sponge to metal, painted surfaces

Table 3. Rubber and Similar Adhesives.—(*Continued*)

Grade Designation	*Kind of Cement, Principal Uses, Etc.*
C-32-S	Crude rubber. Transparent. Elastic bond. Use: Cementing paper, wood, fabric, glass, metal
R-58-T	Crude rubber. Black. Use: Mainly for cementing rubber printing plates to press cylinder saddles
R-434-T	Crude rubber. High bond strength. Use: Cold-patching crude rubber
R-482-T	Reclaim. Gray. Dries with hard film. Use: General utility
R-575-T	Reclaim. Tan. Good tack. High bond strength. Use: All-purpose, fabric to metal, sponge rubber to metal

Cements other than those mentioned in the foregoing list may be obtained either from manufacturer's stocks or on special order to meet virtually every possible condition—particular color, definite drying or vulcanizing time, specialized handling conditions, etc.

In general, cements of the Neoprene and Nitril types are more costly than those made of crude or reclaimed rubber. Also, they are less stable than crude or reclaim cements and thus show a greater tendency to gel. Nitril cements are difficult to handle because they have a tendency to dry tack-free and then must be reactivated by heat before the joint can be made. Sometimes this is an advantage, as in the manufacture of shoes where Nitril cement is used to bond soles to uppers. Cement is applied to the soles and allowed to dry to a hard film. Coated soles may remain in storage for weeks. Then the cement is reactivated with steam, dry heat, or infrared light, and the sole applied to the upper. The storage period between application of cement and joining of the shoe parts simplifies the manufacturing routine.

Special Adhesives

There are some adhesives whose performance has been so outstanding that they merit special consideration. Two such cements are the B. F. Goodrich Vulcalock and Plastilock 500.

Vulcalock Cement. This chemically altered crude-rubber adhesive has worked a sizeable revolution in the industrial use of rubber, permitting the bonding of rubber to metal with an adhesion conservatively stated as 500 to 750 psi. The cement also produces a strong, flexible, waterproof bond between rubber and such materials as concrete and wood and between metals and such materials as leather, fabric, sponge rubber and wood.

Some properties of Vulcalock cement are as follows:

Adhesion: 10 to 750 psi, depending on materials joined and method of application.

Chemical resistance: Superior to ordinary natural rubber.

Durability: Indefinite. Bonds in service more than 10 years have shown no weakening.

Elasticity: Shock, bending, temperature variations do not cause cracking.

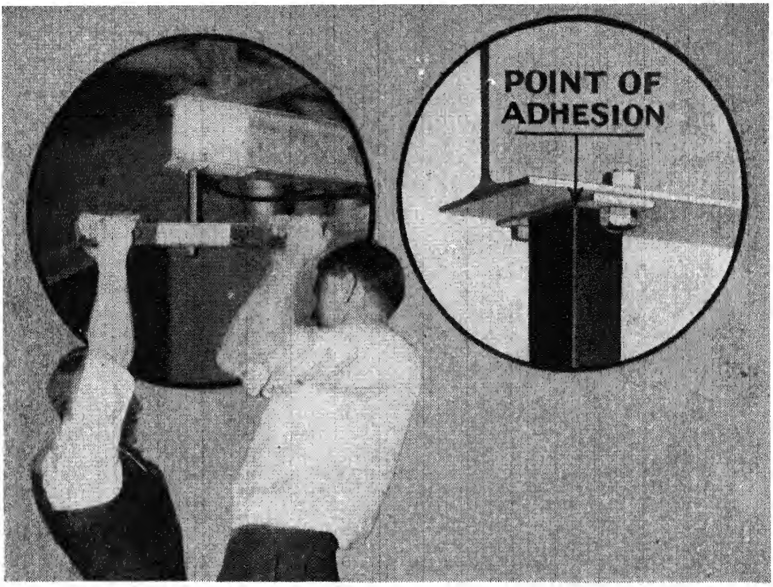

FIG. 3. The weight of two men is supported by a 1-inch-square strip of soft rubber attached at one end with Vulcalock cement to a smooth steel plate.

Heat resistance: Up to 150°F.

Moisture resistance: No water absorption or swelling.

Limitations: Exposure to sunlight may cause harm either during or after application. Cement films are thermoplastic. Cement is inflammable and should be used where ventilation is good.

How to Use Vulcalock Cement. All work except rubber to metal.

1. Clean all surfaces to be joined. Sandblast, pickle, or otherwise clean metal until bright.

2. Thin Vulcalock cement with benzol or naphtha up to one-half its volume, apply a coat to harder surface, and dry 30 minutes at room temperature.

3. Apply one coat of unthinned Vulcalock to other surface, a second (unthinned) coat to harder surface. Let dry until both surfaces are tacky.

4. Place coated surfaces together, roll heavily, and clamp or otherwise apply pressure to assure good contact. Maintain pressure until cement has dried thoroughly, or for several hours at least.

FIG. 4. Using Vulcalock cement to fasten rubber sealing strip around an airplane doorway.

For Rubber-to-metal Vulcalock Bond. 1. Follow the same steps, except (*a*) apply to the rubber surface a nonvulcanizing rubber cement such as B. F. Goodrich No. 4, instead of Vulcalock. (*b*) Apply a coat of the nonvulcanizing rubber cement over the Vulcalock coat. When the

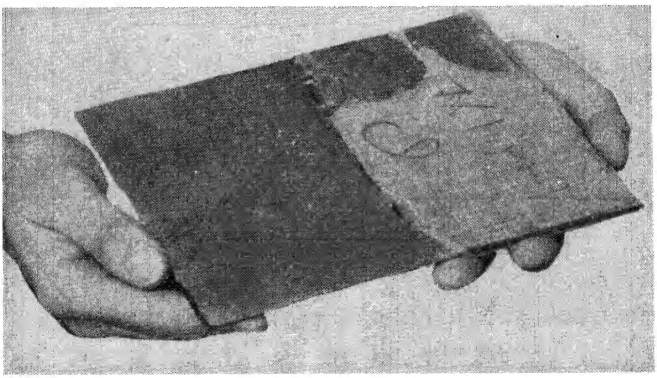

FIG. 5. Test specimen of aluminum bonded to sheet plastic with Plastilock 500 cement. The cement held while the plastic broke away in a joint-strength test.

cement-coated surfaces are tacky-dry, bring them together, roll the joint into good contact, and let dry thoroughly.

2. When a stronger bond is desired, use a heat-vulcanizing cement instead of an air-drying type, and cure the joint by heating it at 281°F for 20 minutes.

The foregoing procedures are intended as general guides only, and special applications may require the working out of a particular routine in conjunction with a cement technician.

PLASTILOCK 500. This is a multipurpose cement posessing remarkable bonding properties. It is a nonthermoplastic, water- and aromatic-oil-resistant adhesive for joining wood to wood; glass to glass and to ceramics, Formica, plastics and wood; metal to metal and to wood, plastics, and ceramics; plastics to themselves and to other above-mentioned materials; mending ceramic objects—in fact, for cementing almost any rigid surfaces.

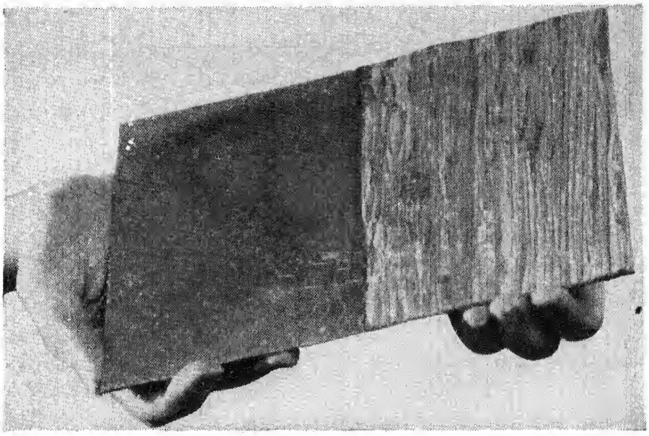

FIG. 6. Here wood and aluminum were bonded with Plastilock 500 cement, and the bond proved stronger than the wood.

This cement may replace rivets and screws in some applications.

Strength of steel-to-steel joint with Plastilock 500 is as follows:

Shear resistance: Up to 3,250 psi.

Tension resistance: Up to 4,000 psi.

How to Use Plastilock 500. 1. Clean dirt, grease, scale from surfaces to be joined.

2. Apply heavy coat of Plastilock 500 to each surface, and dry an hour or more at room temperature. Repeat until three coats have been applied to each surface. Use denatured alcohol for thinning when required and for cleaning brushes.

3. Assemble joint, and secure it against movement, but do not apply much pressure. Preheat in one of the following ways:

Minutes		*Degrees F*
10	at	350
20	at	300
30	at	250

4. Apply pressure with C-clamps or other means, but not to such an extent that the cement is squeezed from the joint. The objective is to secure uniform contact of surfaces. Continue heating in one of the following ways:

Minutes		*Degrees F*
12	at	350
25	at	300
45	at	250

Among the possible applications of Plastilock 500 are the following: fastening of carbon and high-speed-steel drills in special shanks; fastening files and other tools in their handles; securing hammers to handles; permanently locking nuts on bolts and studs in threaded holes; cementing metal to glass, glazed tile, or porcelain; fastening felt to metal where an oil-resistant bond is required, the cement being used like an ordinary glue, without heat.

Covering Power of Rubber Cements

The covering power per coat in square feet for each gallon varies with the cement used. The approximate ranges are:

Table 4

Material	*Square feet*	*Average of 29 cements, sq. ft.*
Wood	20*–250	147
Steel	20 –350	153
Fabric	20 –150	95
Leather	20 –250	126

* This value is for a thick plastic cement developed for covering shoe soles, when applied $\frac{1}{16}$ inch thick. Nearest value for another cement is 75 square feet.

How to Use Air-drying Cements. General suggestions are given in the following list:

1. Roughen surfaces with sandpaper, stiff wire brush, or metal grater.
2. Wash surfaces with benzol or high-test gasoline, or use some of the cement as a cleaner, applying it and then scraping or wiping it off immediately.
3. Apply cement to each surface with brush or other spreader.
4. Let cement dry until tacky.

Caution: For forced drying on damp days, use a warm-air blower. Use of a fan without heat may cause moisture to condense on the cement.

Caution: Do not let sunlight strike cement or cemented surfaces.

5. Apply one or two additional coats and dry each, if necessary to fill up inequalities in surfaces.

6. Bring surfaces together, and roll or otherwise force into absolute contact, with no entrapped air bubbles.

Caution: It is not possible to shift surfaces relative to each other once they touch, so make certain they are brought together properly. Keep joint under pressure as long as possible before use.

HOW TO USE AIR VULCANIZING (ROOM-TEMPERATURE) CEMENTS. Follow the same procedure as for air-drying, but maintain pressure on joint for several days or for the vulcanizing period specified for the particular cement.

HOW TO USE HEAT-VULCANIZING CEMENTS. Follow the same procedures as for air-drying, except that surfaces may dry until no tackiness remains. After bringing the joint together, apply heat and pressure according to vulcanizing directions for that particular cement. Pressure may be removed before joint cools.

HOW TO USE THERMOPLASTIC CEMENTS. Use the same procedure as for heat-vulcanizing, except that pressure must be maintained until the joint cools to room temperature.

HOW TO USE THERMOSETTING CEMENTS. For a typical cement, two or three coats are applied to both surfaces and allowed to dry. Surfaces are clamped lightly together and heated for a specified period. Then clamping pressure is increased enough to ensure good contact but not to force cement out of joint, and heating is continued for another specified period (see Plastilock 500 as applied to steel, page 55).

Note: The roughening of surfaces to be cemented may not always be advisable. Thus, in the joining of steel, better adhesion is often obtained if the surfaces are smooth and freshly polished. Glass should not be roughened.

If a rubber cement dries too much and loses its tackiness before the joint is assembled, it can be retackified by a light application of nonleaded gasoline or other suitable solvent to each surface.

STEP-OFF METHOD OF MAKING CEMENTED JOINTS

Sometimes, in using rubber adhesives, it is necessary to employ several cements in a single joint, because there are some materials to which each cement will not adhere. As an example, in cementing a rubber compound to metal, the following schedule might have to be used:

A cement is applied that will bond to the metal, such as Vulcalock.

Over this is applied a second cement that will adhere well to the first cement but to neither metal nor rubber.

Over the second cement is applied a third cement that will adhere strongly to it and to the rubber.

Sometimes the job can be accomplished with two cements.

Some Limitations of Rubber Cements

Many of the solvents used are highly inflammable; and for that reason, ventilation always should be good and all forms of fire should be kept away.

Many solvents such as benzol are toxic when breathed to any considerable degree or when allowed to come into contact with the skin. Such effects of solvents vary with individual workmen.

Rubber cement, both before and after use, is generally harmed by sunlight, probably because of the action of ozone induced by the light. Therefore, exposure to sunlight must be avoided.

Rapid evaporation of cement solvent may cause atmospheric moisture to condense on cement film and prevent good adhesion.

Average drying time for [illegible] cements is 30 minutes.

Vulcanizing temperatures should be kept within about ±5° of that stated on containers or in directions.

Cement solvents are volatile, and therefore containers must be kept tightly sealed to avoid thickening. Appropriate thinners may be used to restore working consistency.

All rubber cements, especially those having an American-rubber base, should be stored in a cool and dark place.

Dissolving Cemented Bonds. Sometimes it is desired to destroy a cement bond so the joint can be taken apart. Some of the solvents that can be used are listed in Table 5.

Table 5

Type of Cement	*Bond-destroying Solvent*
Uncured crude rubber	Gasoline, benzene
Reclaimed rubber	Gasoline, benzene
GR-S	Gasoline, benzene
Butyl	Gasoline, benzene
Neoprene	Methyl-ethyl ketone
Nitril	Methyl-ethyl ketone

Adhesive Tape

Various kinds of adhesive tapes are made by coating cloth, sheet plastic, etc., with rubber compounds that remain permanently tacky. Commercial splicing compound for electrical work is sheet rubber in tape form. When wrapped around a wire joint, the layers become vul-

canized to each other and form a virtually homogenous covering. Other types of rubber adhesive tapes include the following:

Surgical tapes in sheets and rolls.

Similar tapes for household or commercial uses such as the temporary repairing of hose, wrapping of tool handles, and temporary holding of parts.

Painters' masking tape, cloth or paper backed.

Tapes having a transparent or colored sheet plastic backing, used for decorative work, sealing packages, binding lantern slides, etc.

Friction tape used by electricians for covering joints previously sealed with splicing compound and for numerous miscellaneous uses. Standard width ¾ inches.

Two-in-one tape, which is both a friction tape and a splicing compound. Better adhesion than any friction tape; nonstretching, nonraveling. Standard width, ¾ inch. One ply provides insulation for line voltages up to 220; two plies, for voltages up to 650. Dielectric resistance of single thickness, 8,000 volts.

B. F. Goodrich Splicing Compound Characteristics. This unvulcanized rubber strip 0.027 inch thick (+0.003 inch) and 0.75 inch wide is used principally for wrapping electric wire splices. Friction tape is applied over it for further protection. Its tensile strength is from 155 to 170 psi; its dielectric strength, 8,100 volts. It is made in two grades: "Commercial" for ordinary service, "ASTM" for heavy-duty service.

Rubber Putty

B. F. Goodrich Plastikon Rubber Putty is intended for various types of glazing and sealing. It is of puttylike consistency and is readily applied with a putty knife. Its properties are as follows:

Putty is nonhardening. It shrinks slightly and solidifies to some extent but never becomes brittle.

Elasticity: Nonbrittleness permits putty to absorb vibration and effects of expansion and contraction. Thus it is useful for sealing glass in railway cars, sealing industrial joints where allowance must be made for expansion, etc.

Corrosion resistance: Withstands salt spray and corrosive fumes. Not resistant to strong acids.

Water resistance: Rubber content produces high moisture resistance. Seals against water better than conventional putty.

Air seal: Puttied joints remain airtight, making the material suitable for use in air-conditioning installations.

Drying time: More rapid than for ordinary putty.

Painting: Paint can be applied over rubber putty sooner than over the ordinary kind.

Adhesion: Good adhesion to steel, glass, wood, various plastics, painted surfaces

Colors: Available in red, black, gray, green, and gunmetal.

Consistency: A special gray putty is made for use in caulking guns. Otherwise material is of putty-knife consistency.

Some other applications of rubber putty: Glazing greenhouses, boats, buses, trucks, aquariums, showcases, refrigerated units. Sealing windows and tile roofs of chemical plants. Making leakproof plumbing connections; setting toilet bowls, showers, and tubs. Sealing lamps and reflectors in marine service. In building construction, for sealing stone cornice joints at tops of brick walls, sealing joints in enameled-metal tile to permit expansion and contraction, sealing around sinks and tanks in photographic laboratories. Sealing joints in automobile and truck bodies to retard salt damage, rusting, and entrance of dust.

Rubber putty can be made more tacky with kerosene.

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Chapter 4

LATEX PRODUCTS

The term "latex products" refers to articles manufactured directly from liquid preparations of rubber compounds. Strictly speaking, a latex is an emulsion of rubber and various other ingredients in water, which also may contain chemicals in solution, but the term is also associated with products made from rubber cements and other non-aqueous dispersions or solutions. Crude rubber as obtained from trees and other plants is in the form of a latex. Also, latices are formed from various man-made rubbers and from other synthetic materials such as plasticized vinyl resins.

Latex preparations are often the starting points for such products as rubber coatings on metal, paper, and other bases and for gloves, tubing, thread, sponge rubber, dolls, toy animals and figures, toy balloons, camera bellows, catheters and other surgical and prophylactic items, and adhesives for use with leather, rubber, paper, textiles, and other materials.

Anode Rubber

The term "Anode rubber" is applied to a group of latex products made by various manufacturers under a licensing arrangements with American Anode, Inc., Akron, Ohio. Electrically charged particles composed of the rubber and necessary vulcanizing and other compound ingredients are deposited directly and rapidly, from a liquid preparation, on forms shaped like the article to be produced. After being removed from the latex tank and dried, the deposited rubber is vulcanized in the same manner as milled rubber.

Rubber particles in latex range in size from about 1/50,000 to 1/12,500 inch in diameter, are in a constant state of motion (Brownian movement), and carry small electric charges. As long as the charges are present, the particles repel each other and the rubber remains in dispersion. When the charges are neutralized, the particles come together and form a deposit of rubber. There are two ways in which the rubber deposit can be made to accumulate on patterns or forms:

1. Electrical Deposition. This "rubber plating" method, which originally was used extensively, is now employed only to a limited degree, principally for making rubber labels. The setup is much like that used in the electrodeposition of metals, the latex serving as the electrolyte. The form is made of metal and, when connected to the positive side of a direct-current source, becomes the anode. The current neutralizes the charges on near-by latex particles, causing them to coalesce on the anode.

Rubber Labels. The electric-current method is used in the making of labels from natural-rubber latex. The anode is a sheet of zinc in which the letters, figures, or other characters have been etched by acid—exactly as a zinc printing plate is made. The surrounding surface is coated with insulation. Rubber is deposited, by the action of the current, in the etched cavities only. When a sufficient thickness has been built up, the plate is removed and the characters transferred to a rubber base. The rubber may then be vulcanized in steam to produce a raised-letter effect or squeegeed against a chromium-surfaced plate and vulcanized to produce a glossy, even surface. A semigloss surface is formed when the rubber is press-cured in "books" of Holland cloth. Such rubber labels are used for marking hose, belts, tires, and other rubber products. They may be cemented or vulcanized to either crude- or American-rubber compounds, and they are adaptable to nonrubber applications where the chemical or cushioning properties of rubber would be an advantage. A wide range of colors is possible.

2. The "Wireless" Anode Process. The method by which practically all Anode products are now manufactured does not make use of electric current carried over wires, although it still utilizes the electrical charges on latex particles. These charges are neutralized by associating with a previously deposited coagulant which gradually releases positively charged ions when dipped into the latex. These ions neutralize the charges on near-by latex particles, causing them to be deposited on the form. The building up of a rubber layer does not halt this production of positive ions, which continue to diffuse out through the deposit and cause still more rubber particles to be added to the layer. Thus the thickness of the deposited rubber can be controlled simply by regulating the time the form is in the latex. This ability to build up the desired thickness by a single dip into the latex is one of the most valuable features of the process.

Characteristics of Anode Rubbers. The chief features of rubber articles produced by the Anode process can be summarized as follows:

1. *Single Dip.* The rubber deposit that is to form a glove or other product can be built up to the desired thickness by a single immersion in the latex. This may be compared with multiple-dip methods, which require the form to be dipped repeatedly into a cement solution and

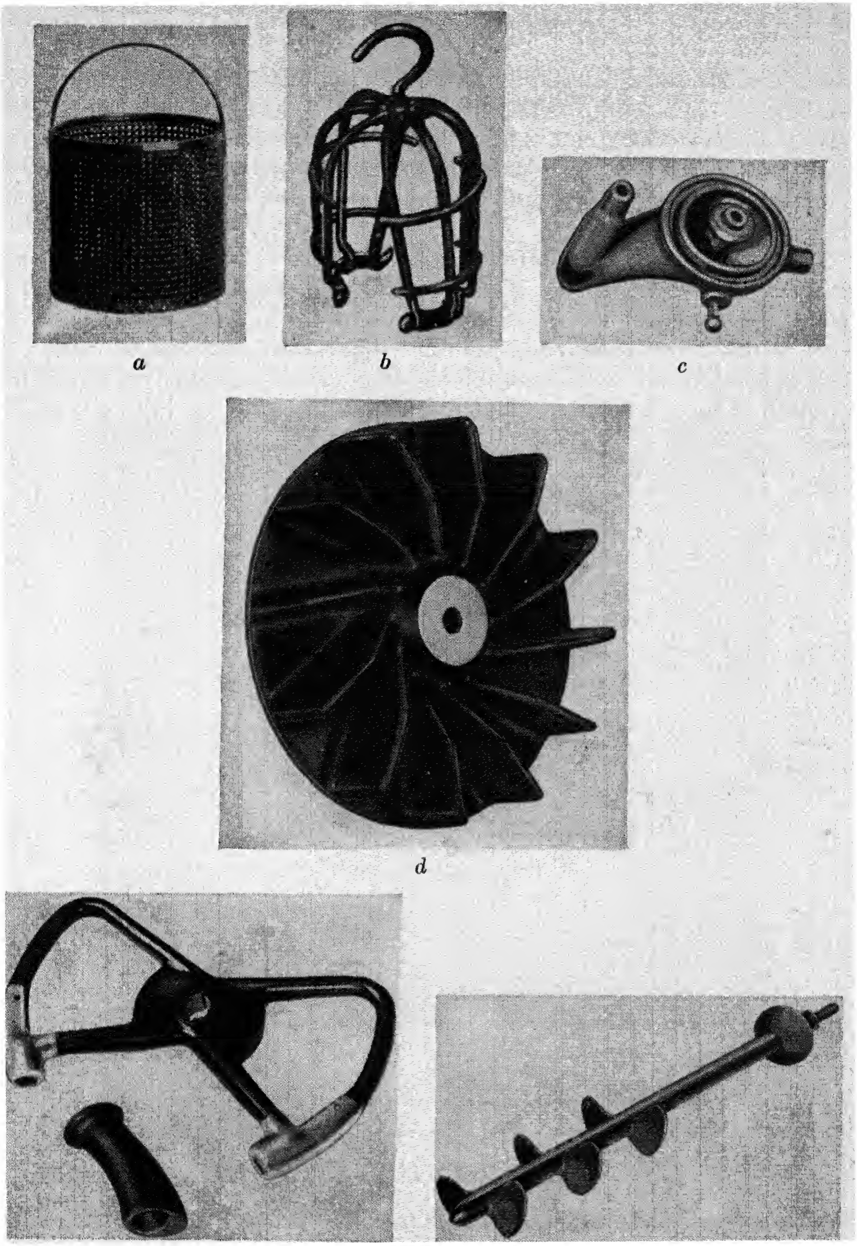

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FIG. 1. Examples of shapes that can be coated with latex rubber by the Anode process. (*a*) Perforated metal basket. (*b*) Lamp guard. (*c*) Fitting for chemical equipment. (*d*) Cleaner fan. (*e*) Aircraft controls. (*f*) Mixer blades.

exposed to air between each dip to permit the film to dry. Such alternate dipping and exposure may cause the rubber to pick up dirt from the air, to blister, to form thick and thin spots, to separate between plies, and to acquire other defects. The one-dip process eliminates such hazards. In some cases, an Anode product is made by more than one dip, as when covering sharp edges.

2. *Uniform Mix.* The latex is kept at all times at the specified consistency. The original latex is filtered and centrifuged to concentrate it, to ensure cleanliness and freedom from dirt in the product, and to remove some of the natural-occurring proteins, sugars, and enzymes.

3. *High Strength.* Because of the absence of milling, the original strength of the rubber is not affected when it is transferred directly from latex to product.

4. *Long Product Life.* Anode products have long shelf and service life.

It is possible to make pure-gum milled stocks that are reasonably transparent, but they have characteristics that limit their usefulness. Milled tubing, etc., in order to exhibit satisfactory physical properties, must contain ingredients that destroy transparency. Tubing and other products manufactured directly from latex can be made sufficiently transparent to permit air bubbles, liquid movement, and colors to be seen through them. This is accomplished without the loss of other desirable properties.

Latex products have been made from the kinds of rubber listed in Table 1.

Types of Rubber Used

Table 1

Compounds of	*Durometer Hardness Range*
Crude rubber:	
Soft	30–80
Hard	90 ± 5
GR-S, hard	90 ± 5
Neoprene, soft	35–75
Nitril (Hycar)	35–75

Latex products are made also from plasticized vinyl compounds.

"Dip-and-dry" Products

Some manufacturers still make rubber gloves and various other products by the older dip-and-dry or cement-dipping method. The rubber compound is in the form of a solution that is virtually a rubber cement. The form is dipped repeatedly into the solution, removed, and each

coating allowed to dry. When a sufficient rubber thickness has been built up, it is vulcanized by exposure to steam. In the so-called "acid-cure" process, now rarely used, vulcanization is effected by sulfur chloride in an acid solution. A latex dip in which the rubber and other ingredients are in water can be used in the dip-and-dry method instead of a solution made with a rubber solvent.

Typical Latex Products

Latex processes have been used for making a considerable variety of rubber products ranging from gas-decontamination gloves and electri-

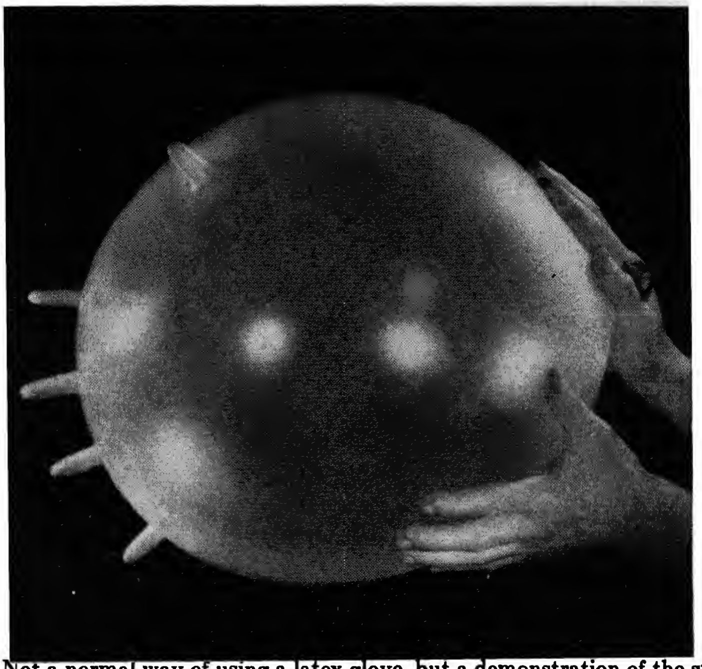


Fig. 2. Not a normal way of using a latex glove, but a demonstration of the strength of such rubber compounds, whose tensile strength may exceed 4,000 psi.

cian's gloves to surgical tubing and toys for infants. New applications of latex rubber are being envisioned almost every day. The following products are typical:

Gloves. Strength, uniformity, and longer life are among the superiorities claimed for Anode gloves in comparison with cement-dipped and similar kinds. On the other hand, dipped gloves are softer and more pliable.

The following are some typical Anode gloves:

1. *Electricians' Gloves.* These are made from crude-rubber latex, and black in color. Class A gloves are tested at 16,000 volts and have a rubber thickness ranging from 0.050 to 0.070 inch. Class B gloves are tested at 14,000 volts, and have a thickness range of 0.044 to 0.050 inch. All electricians' gloves are coded to indicate the date of their manufacture. After three years in storage, these gloves may be returned to the manufacturer for retesting and reclassification.

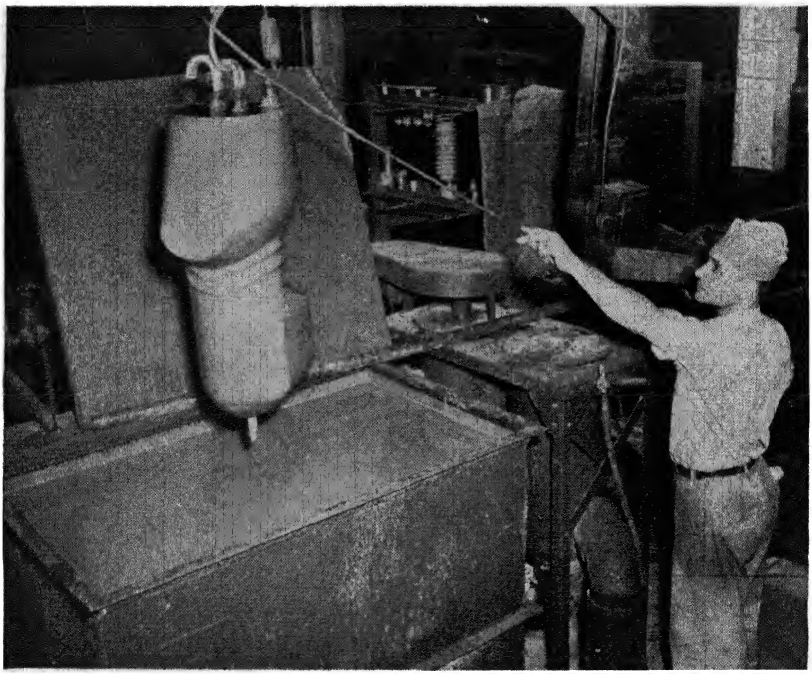


FIG. 3. A sandblaster's helmet, coated with rubber by the Anode process, has just been raised from the tank of latex.

2. *Acid-handling Gloves.* These are made from crude rubber or Neoprene and are useful in connection with the handling of plating solutions, storage battery acid, pickling acids, etc.

3. *Canners' Gloves.* Fruit cannery workers use these gloves. Surfaces are made with a frosted or skinlike texture to minimize slipping.

4. *Surgeons' Gloves.* These are made of crude-rubber latex and are brown or "white" in color. Thickness is around 0.010 inch. As a stunt, such gloves have been inflated to form balloons large enough to encompass a half-grown child. Also, one of these gloves can be stretched several feet.

5. *Household Gloves.* These are similar to surgeons' gloves, but of thicker rubber, and are not held to such rigid specifications. Surfaces may be frosted to minimize slipping.

Tensile Strength of Anode Gloves. Crude-rubber surgeons' and indus-

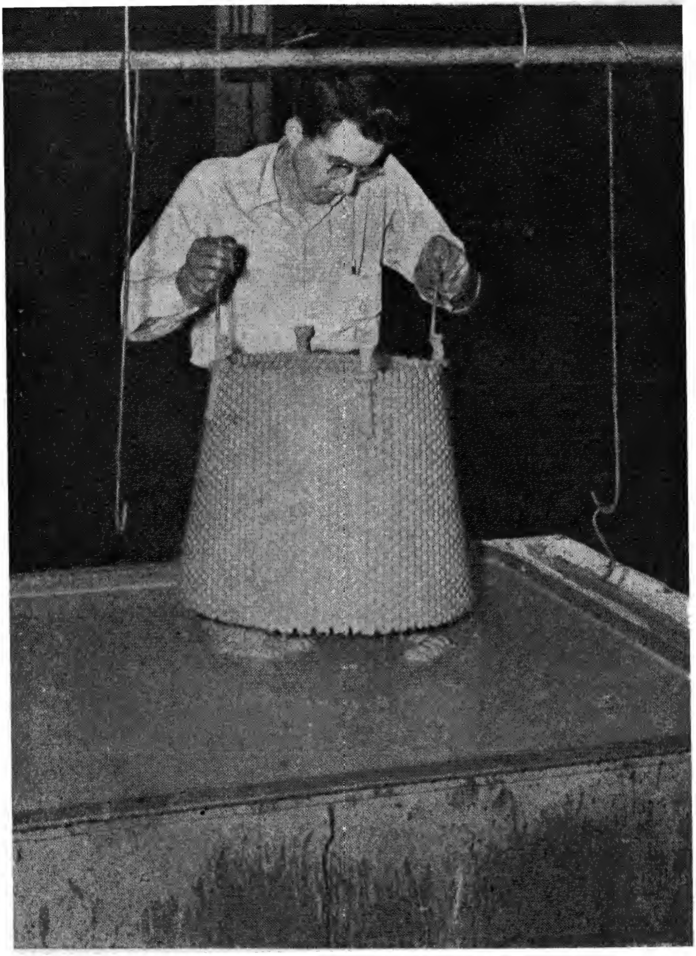


FIG. 4. Draining excessive latex from perforated metal screen. Next step is to vulcanize the coating.

trial gloves have a tensile strength of about 4,000 to 6,000 psi; Neoprene industrial gloves, around 3,000 psi.

Tolerance. Industrial gloves made by the Anode process are held to ± 0.002 inch. Acid gloves are held to ± 0.004 inch. The thickness range of electrician's gloves is stated on page 66.

Coated Articles. The Anode process, being a form of rubber plating, lends itself admirably to the covering of metal articles for the purpose of resisting chemical action and abrasion or for providing a cushioning effect.

Materials That Can Be Covered. Most metals can be covered, except magnesium, which is too porous; imprisoned air causes severe bubbling and blistering during vulcanization.

Aluminum, when highly polished, must be sandblasted before application of the rubber.

Stainless steel, in most of its forms, must be sandblasted.

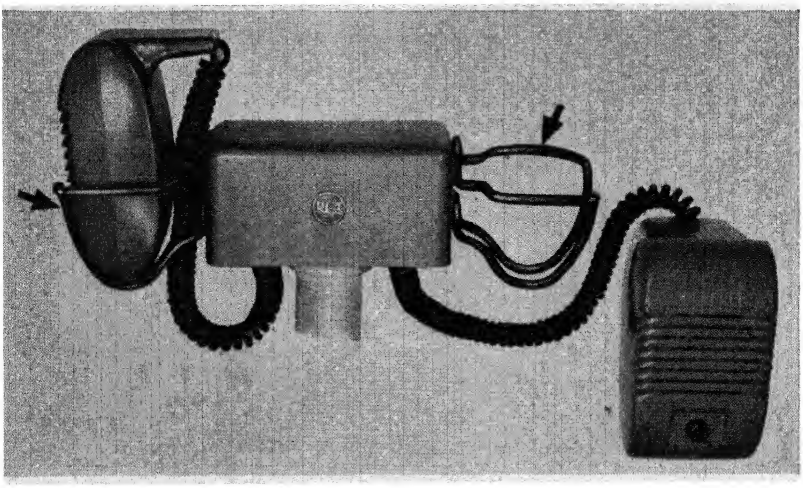


Fig. 5. These compact loudspeakers, which carry drive-in theater programs directly into patrons' cars, are stored in metal brackets (indicated by arrow) covered with latex rubber by the Anode process.

Copper, formerly difficult to coat with latex rubber, can be successfully covered by recently developed methods.

Other Articles. Articles that have been covered with latex rubber include perforated metal baskets used in the electroplating of small metal parts such as bolts and nuts; baskets and racks made of wire, for holding dishware, etc.; wire baskets or trays used in the volume processing of photographic prints; filter press plates; metal racks used for suspending articles in an electroplating bath; sandblasters' helmets, in which the one-piece latex covering effectively seals out dust and resists abrasive action of the sand; hooks for attaching drive-in theater loudspeakers to patrons' car.

Cover Thickness. The usual thickness of covering on metal articles ranges from $\frac{1}{64}$ to $\frac{1}{8}$ inch. Tolerance in cover thickness on small articles falls within $\frac{1}{100}$ inch. On large pieces, the tolerance is $\pm\ \frac{1}{64}$ inch.

Design Pointers. In plants that do Anode work, difficulties sometimes arise because metal articles sent in for covering have faults that are

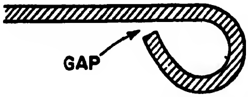


Fig. 6*a*. Rolled edges of metal containers, etc., to be covered by the Anode process should be made so edges come against metal and not with a gap as shown. Whereas covering often will bridge gap, there may be unbridged places where corrosive liquids can reach metal.

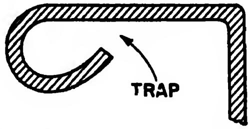


Fig. 6*b*. This shows another type of rolled edge that may cause trouble if bead is not fully formed and a gap results.

traceable to unfamiliarity with the Anode process. Some design details that should be kept in mind include the following:

If there are parts of the article that are rough or that include angles where air is easily trapped, it is difficult to produce a deposit because the entrapped air prevents the coating from sticking; or when it does stick, blistering results during subsequent vulcanization wherever air was entrapped.

Rolled or Folded Edges. Edges should be turned back until they touch the metal surface. A plating basket or other metal article having an edge that is rolled or folded only partway around cannot be easily covered with latex rubber because the deposit may not enter the gap along the folded edge. When edges are turned as far as possible, the rubber covering will bridge any slight gaps that may occur.

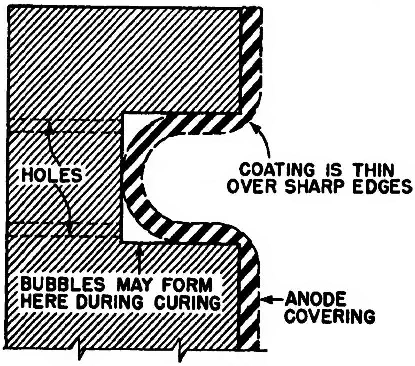


Fig. 6*c*. A square groove in a surface to be covered with Anode rubber is undesirable. The Anode covering tends to take a rounded shape in bottom of groove, instead of following metal surface. In the corners of the groove, the rubber may not fill completely, so that in curing, bubbles are formed beneath coating. One way of counteracting bubbles is to drill small holes as shown, to bleed off gases. Anode covering tends to thin out over sharp edges and corners; when possible, such edges and corners should be given a generous radius.

Grooves. Methods of lining containers, channels, grooves, etc., have been developed to counteract shrinkage of latex. Holes are drilled to permit the rubber to flow through the metal and form anchor fingers. Cements and other treatments are applied to the metal before covering. In a square channel on an inside surface, the rubber may pull loose from

the square corners if such precautions are not taken. Also, the portion of rubber lying within a square groove will not be square to correspond with the metal but will be rounded.

Sharp edges and corners should be avoided whenever possible. The coating always tends to be thinner along such edges, and multiple dipping is often necessary to obtain adequate thickness. By giving edges and corners as much radius as possible, a more uniform covering is obtainable with minimum effort.

SCREENS AND OTHER PERFORATED PARTS. During deposition, an Anode covering tends to bridge small holes in the metal form. Openings as large as 1/8 inch are easily bridged. This is, in many instances, an advantage, for small blemishes are thus neutralized. But in the case of perforated metal screens, baskets, and any other pieces having holes that are to be kept open, special design precautions have to taken.

In its wet state, an Anode covering made from crude-rubber latex is 30 per cent heavier gauge than in its dry state. When an American-made rubber is being used, the difference is 50 per cent. Because of this, a hole that would be large enough for a dry or cured coating may be bridged by the same coating when wet. A general rule to follow is to make the diameters of all holes at least 6 times the thickness of the finished coating when the holes are to be left open and when crude-rubber latex is to be used. When an American-rubber coating is to be applied, the holes should be at least 7½ times the coating thickness.

LATEX TUBING. For surgical and laboratory use, such tubing is made from crude-rubber latex and is amber in color, with a high degree of transparency. It can be made in continuous lengths up to 50 feet and to any practical diameter. Wall thicknesses and diameters usually made are given in Table 2.

TABLE 2

I.D., in.	*O.D., in.*	*Wall thickness, in.*
1/8	3/16	1/32
3/16	5/16 or 3/8	1/16 or 3/32
1/4	3/8 or 7/16	1/16 or 3/32
5/16	7/16 or 1/2	1/16 or 3/32

Tubing dimension tolerances are 1/128 inch in thin wall gauges and 1/64 in thicker gauges.

PEN SACS AND DIAPHRAGMS. At one time, practically all the quality fountain-pen sacs and diaphragms used in the United States were made of

Anode rubber. Uniformity of thickness, freedom from flaws, and long service life are among the factors that brought this about. When a pen will not hold the quantity of ink for which it was designed (around 60 drops for some sizes), the cause sometimes is found to be a sac or diaphragm that has become flattened, creased, or otherwise distorted through improper assembly.

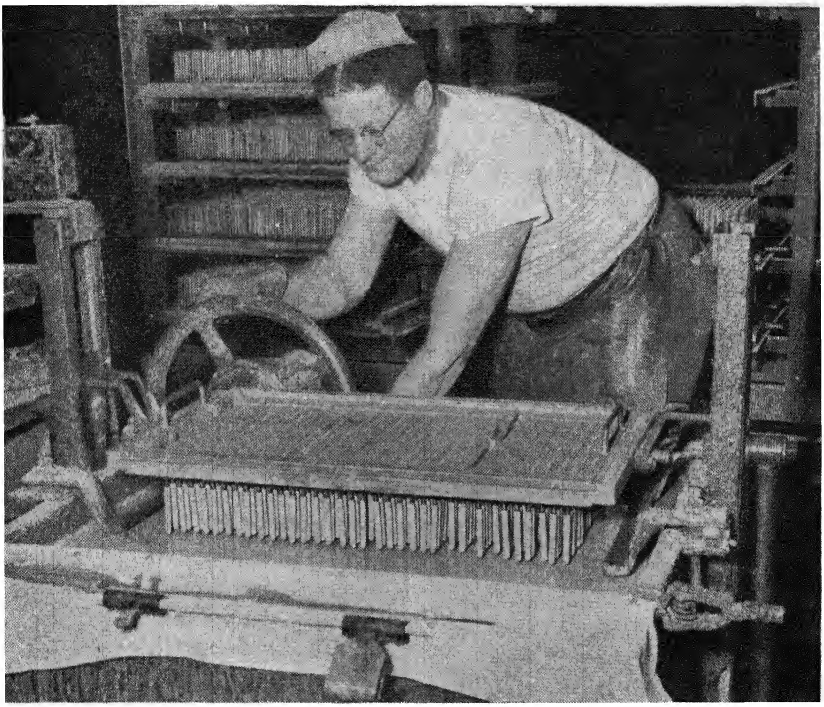


FIG. 7. Manufacturing latex-rubber fountain-pen sacs.

Pen sacs, being short tubes closed at one end, are made on forms that project from a common base like the bristles of a brush. Specialized uses have been found for such products: One radio manufacturer found that a portion of a sac could be used for cushioning a delicate piece of electronic equipment. Sacs also can be used to seal small phials or glass tubes containing medicinal or other preparations.

Some ball-type pens have ink cartridges made of hard rubber.

LININGS. Aside from the lining or covering of plating baskets and similar articles with latex rubber, the Anode process is being used to make rubber linings without seams for tobacco pouches. The rubber is deposited

on a form from which it is stripped after vulcanization. It is also possible to rubber-plate inside surfaces of narrow-mouthed containers. When a coating is deposited on the outside of a form from which it will be stripped after curing, the dimensions should be such that the rubber will be stretched, during removal, to no more than 4 inches to the inch (300 per cent). Thus an opening measuring 3 inches around would permit a maximum circumference of 12 inches where the rubber is to be stretched over the form during removal.

Miscellaneous Properties

In general, the physical and chemical properties of latex-rubber compounds are the same as those applicable to corresponding milled-rubber compounds.

Tensile strength of gloves has been noted. The tensile properties of pure gum latex rubber are higher than for pure gum milled rubber. Tensile strength of crude latex rubber is about 40 to 50 per cent greater than the tensile strength of American-rubber latex compounds.

Abrasion resistance is not so high as that attainable with milled-rubber compounds; latex rubber, when loaded with abrasion-resisting pigments, does not have the abrasion resistance obtainable with a mill-mixed stock of similar composition. Neoprene latex rubber has lower abrasion resistance than crude-rubber latex deposits.

Permanent set of latex products is normally slight.

Elongation of rubber articles made directly from natural latex is usually around 850 to 900 per cent. Neoprene latex gives stocks of similar elongation.

Temperature range of crude latex rubber is about the same as for corresponding milled compounds. For Neoprene and other American rubbers, the useful range extends from about -22 to 220°F.

Toxicity. Rubber articles made from crude (tree) rubber latex contain a higher percentage of original protein than milled natural rubber. In rare cases, this may cause a skin sensitization which may result in an allergic reaction on a person who has a sensitivity to proteins. Otherwise, latex rubber, crude or American-made, is no more toxic than milled compounds.

Blooming of sulfur from latex rubber is a controllable factor. In tubing, etc., it can be made negligible. In the case of fountain-pen sacs, high blooming is desirable because the sulfur acts as a lubricant when the sacs are flexed and aids in the original installation of the pen mechanism.

Cementing. Latex rubber is difficult to cement to itself or to milled crude and American rubber.

Cutting. Products made of crude-rubber latex have a lot of "nerve" and therefore are difficult to trim and cut. Rubber made from an American-rubber latex can be cut with relative ease.

Chemical Resistance. For maximum resistance to acids, hard rubber made from crude- or American-rubber latex is used. For maximum resistance to oils, Nitril rubber is employed.

Chapter 5

V-BELTS AND SHEAVES

Power-transmitting belts made of crude and American rubbers and having cross sections resembling the letter "V" have come into extensive use in industry because of a number of advantages, which include the following: compactness, quiet operation, nonslipping grip between belt and sheave, absorption of shock, smooth starting, cleanliness (no dressing or lubricant required), long service life, low cost, and light bearing loading.

The construction of V-belts varies among manufacturers and according to the service for which belts are designed. The following types may be taken as typical:

1. LIGHT-DUTY (FRACTIONAL-HORSEPOWER OR "FHP") V-BELTS. These are used for light power transmission such as driving small air compressors, refrigeration equipment, woodworking machinery, drill presses, and lathes. More technically, the term "light-duty" or "FHP" employed in connection with V-belts indicates all single-drive belts and those used on refrigerators, motor vehicles, domestic appliances, and other equipment having multiple drives of not more than three belts, each belt having a top width of less than 7/8 inch, or no more than two belts whose top widths do not exceed 1 1/4 inches, and also those used on domestic appliances and commercial refrigerators having motors with a name-plate rating of not more than 3 horsepower.

2. MULTIPLE V-BELTS. This group includes all industrial V-belts not in the light-duty classification. Generally, they are used in multiple on drives ranging up to several hundred horsepower and run in matched sets on multigrooved sheaves or on a grooved sheave and a flat pulley.

3. AUTOMOTIVE V-BELTS. These are not classed as an "Industrial" item.

Textile-cord-grommet V-belts. They contain endless cables or grommets made by combining cotton or other textile cords. The belts have high strength, low permanent stretch, and better shock absorption and flexing ability than the wire-grommet belts mentioned below. Textile-cord-grommet V-belts can be used to replace standard V-belts but should not be mixed with them on multiple drives because of the lower stretch permitted by the cord grommet.

Wire-grommet V-belts. This type contains endless cables or grommets made of steel wire, which float in beds of solid rubber. Such belts posses great strength, high flexibility, cool-running properties, high resistance to stretch, and long life. They are used where ordinary V-belts would be too weak and stretch too much, where considerable power must be transmitted with few belts, to replace chain and gear drives where space is limited, for slow-speed drives that normally would require gears or

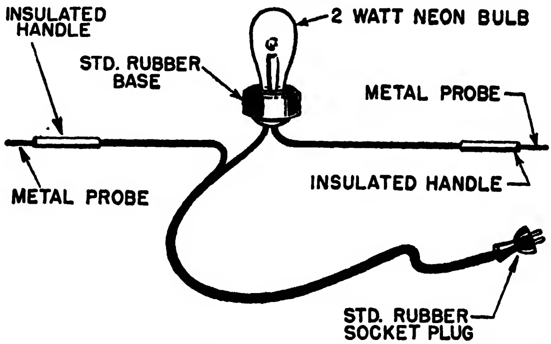


FIG. 1. Test device for identification of static-control V-belts. *Directions:* Connect one wire of a standard lamp cord (equipped with plug) to one terminal of a socket for a 2-watt neon glow lamp, and connect other lamp-cord wire to a battery clip or metal probe equipped with an insulated handle. Connect a length of wire to other terminal of lamp and equip it with a clip or probe. At two places along belt, moisten the rubber all the way with Aquadag, leaving a 4-inch dry portion between. If you have no Aquadag, dip belt into water, leaving dry area between two wet ones. Place test-lamp probes or clamps against the wet spots and plug cord into 110 to 125-volt a-c line. Be sure belt is held so the section between clamps is suspended in air or resting on an insulating surface. If the neon lamp glows, the belt is a conducting (static-control) type. If it does not glow, the belt is an ordinary type. In a similar way, any product such as hose or flat belt can be tested to determine whether it is made of a conducting material.

chains, for applications where weight must be conserved, and for replacing standard belts that fail prematurely.

Static-control V-belts. Friction between ordinary V-belts and their sheaves often generates static electricity, which, by creating high potential differences, may cause shock to operators or become a hazard in plants where explosive materials are handled. Static-control V-belts were developed to drain off such electrical charges before they reach dangerous proportions. The rubber used in the covers is compounded in such a way that the belts actually are conductors of static charges but will not conduct ordinary electric currents such as those used to operate motors and lights. Some static-control belts are made by merely coating the surface with conducting materials.

To ensure proper operation of a static-conducting belt, the machine on which it is used should be grounded properly, as by running a stranded

copper wire or strip from the machine to a water pipe. The ground conductor need not be insulated.

Open-end V-belting. Sometimes it is not feasible to install endless V-belts, yet the various V-belt advantages are highly desirable. For example, in a line-shaft drive, endless construction might make it necessary to dismantle the shaft so the belts could be placed around the shaft sheaves. For use in such cases, open belts with ends connected by metal fasteners were developed. When properly installed, the fasteners do not touch the sheaves, and operation is quiet.

Oil-resisting V-belts. Lubricating or other oils cause crude-rubber and many American-rubber compounds to deteriorate and therefore are injurious to ordinary types of V-belts. Belts having covers made of oil-resisting rubber will withstand oil spatter and practically all other oily conditions.

V-BELT ANATOMY. The internal structure of standard V-belts varies considerably, as an inspection of the cross sections of light-duty and multiple V-belts will reveal. The strength of a V-belt is concentrated in its "backbone" of cords, which is located in the upper, wider portion. These cords, in the best belts, are impregnated with and embedded in a mass of solid rubber which, by reducing friction between individual strands or fibers, retards heat build-up. The use of a solid rubber cushion toward the narrower, bottom part of the belt improves flexibility and increases shock absorption. In starting, momentary stresses greater than those encountered in running must be withstood, and this rubber cushion acts as an absorber for the sudden pull, thus protecting the cords and cover. When the belt travels around a sheave, the narrower portion is compressed, and the solid rubber cushion must withstand such distortion without accumulating excessive heat. Special cool-running rubber compounds have been developed. The fabric-and-rubber belt cover acts as an envelope to resist wear and protect the inner structure.

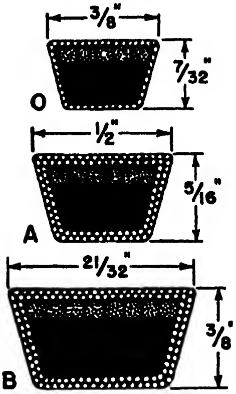


FIG. 2. Cross-sectional dimensions of standard light-duty (fractional-horsepower) V-belts.

Maximum power is delivered by a belt that grips the sides of the sheave grooves without slipping. In a straight-side belt, the sides try to bulge outward as the belt bends around the sheave, but the sheave groove walls act as a nonyielding barrier. The resulting pressure between belt and groove walls tends to lock the belt in the grooves. Yet when the belt straightens as it leaves the groove, the locking pressure is relieved without introducing appreciable drag.

When a V-belt is matched properly to its sheaves, excessive belt tension is not necessary to prevent slipping.

V-belt Cross Sections

V-belts are classified according to their cross-sectional dimensions, each size being indicated by letters or numbers, as shown in Table 1.

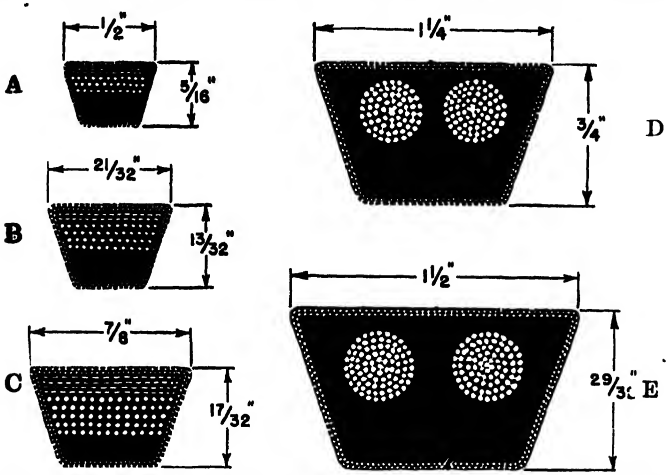


Fig. 3. Cross-sectional dimensions of standard multiple V-belts.

Table 1. Standard V-belts*

Light-duty (FHP) group†

Letter designation	*No. designation*	*Nominal top width, in.*	*Nominal thickness, in.*
O	0000	3/8	7/32
A	1000	1/2	5/16
B	2000	21/32	3/8

Multiple V-belt group‡

Letter designation	*Nominal top width, in.*	*Nominal thickness, in.*
A section..................	1/2	5/16
B section..................	21/32	13/32
C section..................	7/8	17/32
D section..................	1 1/4	3/4
E section..................	1 1/2	29/32

* The angle between sides of standard belts is commonly 40 degrees.

† Also numerous nonstandard sizes.

‡ Also railroad V-belts having top widths of 3/4, 1 and 2 inches, plus other special sizes.

TABLE 2. SUGGESTED LIGHT-DUTY V-BELT CROSS SECTION FOR VARIOUS HORSEPOWER AND SPEEDS*

Horsepower of motor	*Motor speed, rpm*	
	1,725	*1,150*
Normal duty:		
1/8 (0.125)	*A*	*A*
1/6 (0.165)	*A*	*A*
1/5 (0.20)	*A*	*A*
1/4 (0.25)	*A*	*A*
1/3 (0.333)	*A*	*A*
1/2 (0.50)	*A*	*A* or *B*
3/4 (0.75)	*B*	*B*
Heavy duty:		
1/8 (0.125)	*A*	*A*
1/6 (0.165)	*A*	*A*
1/5 (0.20)	*A*	*A*
1/4 (0.25)	*A*	*A*
1/3 (0.333)	*A*	*B*
1/2 (0.50)	*B*	*B*
3/4 (0.75)	*B*	*B*

* In above table, *A* = series 1,000 V-belt; *B* = series 2,000 V-belt.

V-BELT SHEAVES

A complete V-belt drive consists of one or more V-belts running on two or more sheaves or pulleys. Usually there are only two sheaves, although in automotive and some other installations one belt may be operated on three on more sheaves. When both sheaves are grooved, the assembly is known as a V-V drive. When one sheave is grooved and the other flat, the assembly is called a V-flat drive.

By proper matching of sheaves, any desirable speed ratio and center-to-center distance between sheaves may be obtained. There are numerous stock sizes, and manufacturers' lists should be consulted when selecting replacement sheaves or designing new V-belt drives. Although it sometimes may be necessary to use nonstock sizes, the designer should try to select standard sizes of both sheaves and belts.

SHEAVE DIMENSIONS

BORES. Bores of light-duty sheaves generally run from 1/2 to 2 1/4 inches. Bores of multiple V-belt sheaves run from 1/2 to 8 inches and more.

Bushings. Standard bushings are available for fitting stock sheaves to any shaft.

Key Seats. American standard key seats and square keys are used for all light-duty sheaves. Multiple V-belt sheaves and bushings use both ASME standard square and flat keys, with key seats to match.

Table 3. Standard Key Seats for Light-duty Sheaves

Diam. of bore, in.	*Size of key seat in hub and shaft, in.*	*Size of key, in.*
$\frac{1}{2}$ – $\frac{9}{16}$	$\frac{1}{8} \times \frac{1}{16}$	$\frac{1}{8} \times \frac{1}{8}$
$\frac{5}{8}$ – $\frac{7}{8}$	$\frac{3}{16} \times \frac{3}{32}$	$\frac{3}{16} \times \frac{3}{16}$
$\frac{15}{16}$–$1\frac{1}{4}$	$\frac{1}{4} \times \frac{1}{8}$	$\frac{1}{4} \times \frac{1}{4}$
$1\frac{5}{16}$–$1\frac{3}{8}$	$\frac{5}{16} \times \frac{5}{32}$	$\frac{5}{16} \times \frac{5}{16}$
$1\frac{7}{16}$–$1\frac{3}{4}$	$\frac{3}{8} \times \frac{3}{16}$	$\frac{3}{8} \times \frac{3}{8}$
$1\frac{13}{16}$–$2\frac{1}{4}$	$\frac{1}{2} \times \frac{1}{4}$	$\frac{1}{2} \times \frac{1}{2}$

Diameters. Sheaves are selected according to pitch diameter. The actual outside diameter is of secondary importance. The pitch length of a V-belt is the length measured along the neutral axis of the belt. The pitch diameter of a sheave is the diameter measured to this neutral axis line when the belt is in the sheave groove. Pitch diameters of sheaves are used in all calculations of speed ratios.

Grooves. Top width and angle of sides are the important dimensions in V-belt sheave grooves. The depth of a groove is always greater than the thickness of the belt, and the belt should never ride so deeply in the groove that it touches the bottom. When open-end belts are used, the depth of the groove provides clearance for the metal connectors. The angle of a pulley groove is that measured between the intersection of lines extending the groove sides. The angle of the sheave groove is slightly less than the angle between the belt sides, the difference becoming less as the sheave diameter increases.

Often a V-belt can be used on a sheave grooved for the next larger belt cross section. Thus, in the case of light-duty belts, an *A*-section groove will accommodate a No. 1,000 belt only, but a *B*-section groove, while intended primarily for No. 2,000 belts, will also accommodate the No. 1,000 size. Whenever a smaller belt is used, the effective pitch diameter of the sheave is decreased. In the case of Nos. 1,000 and 2,000 light-duty belts, the pitch diameter of the *B*-section sheave is 0.4 inch less when a No. 1,000 belt is used.

Standard groove dimensions for multiple V-belt sheaves are shown in Table 4.

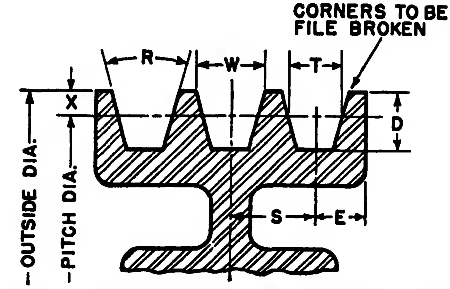


FIG. 4. Cross section of multiple V-belt sheave.

TABLE 4. STANDARD GROOVE DIMENSIONS FOR MULTIPLE V-BELT SHEAVES*

Belt	Pitch diam., in.	α, deg	W	T	S	D	E	X
A	Under 2.4 2.4–2.99 3.0–5.4 Over 5.4	30 32 34 38	0.492 0.500 0.507 0.521	0.392	5/8	1/2	3/8	3/16
B	Under 3.6 3.6–4.59 4.6–7 Over 7	30 32 34 38	0.639 0.648 0.658 0.677	0.505	3/4	11/16	1/2	1/4
C	Under 5 5–5.99 6–7.99 8–12 Over 12	30 32 34 36 38	0.861 0.875 0.889 0.904 0.918	0.660	1	29/32	11/16	3/8
D	Under 8 8–9.99 10–12.99 13–17 Over 17	30 32 34 36 38	1.226 1.243 1.260 1.276 1.293	0.992	1 7/16	1 1/8	7/8	7/16
E	Under 12 12–15.99 16–24 Over 24	32 34 36 38	1.478 1.499 1.521 1.542	1.155	1 3/4	1 5/16	1 1/8	9/16

* Dimensions in this table were approved as standard by the Multiple V-Belt Drive Association on Sept. 7, 1943.

Types of Sheaves

Sheave types include the following:

Cast-iron Sheaves. These are machined from cast iron. In smaller sizes, hub and rim are joined by solid web; in larger sizes, by spokes (arm type).

Table 5. Dimensions and Weights of Cast-iron Light-duty Sheaves for 1,000 Belt Only

Pitch diam. in. for No. 1,000 belt	*Outside diam., in.*	*Standard stock bores, in.*	*Max. bore*	*Dimensions*					*Net wt., lb*
				H	*L*	*F*	*P*	*C*	
2.0	2.3	½ ⅝ ¾	¾	1½	1	¾	½	¼	0 6
2.2	2.5	½ ⅝ ¾	¾	1½	1	¾	½	¼	0 7
2.4	2.7	½ ⅝ ¾	¾	1½	1	¾	½	¼	0 8
2.6	2.9	½ ⅝ ¾ 1	1	1¾	1	¾	½	¼	0 9
2.8	3.1	½ ⅝ ¾ 1	1	1¾	1	¾	½	¼	1 0
3.0	3.3	½ ⅝ ¾ 1	1	1¾	1	¾	½	¼	1 1
3.2	3.5	½ ⅝ ¾ 1	1	1¾	1	¾	½	¼	1 2
3.5	3.8	½ ⅝ ¾ 1	1	1¾	1	¾	½	¼	1.3
3.7	4.0	½ ⅝ ¾ 1	1	1¾	1	¾	½	¼	1 4
4.0	4.3	½ ⅝ ¾ 1	1	1¾	1¼	¾	½	..	1 5
4.2	4.5	½ ⅝ ¾ 1	1	1¾	1¼	¾	½	..	1.7
4.5	4.8	½ ⅝ ¾ 1	1	1¾	1¼	¾	½	..	1 8
4.7	5.0	½ ⅝ ¾ 1	1	1¾	1¼	¾	½	..	1 9
5.0	5.3	½ ⅝ ¾ 1	1	1¾	1¼	¾	½	..	2.2
5.2	5.5	½ ⅝ ¾ 1	1	1¾	1¼	¾	½	..	2.2
5.5	5.8	½ ⅝ ¾ 1 1³⁄₁₆	1³⁄₁₆	2	1¼	¾	½	..	2.4
5.7	6.0	½ ⅝ ¾ 1 1³⁄₁₆	1³⁄₁₆	2	1¼	¾	½	..	2.5
6.0	6.3	½ ⅝ ¾ 1 1³⁄₁₆	1³⁄₁₆	2	1¼	¾	½	..	2 6
7.0	7.3	½ ⅝ ¾ 1 1³⁄₁₆	1³⁄₁₆	2	1¼	¾	½	..	3 3
8.0	8.3	½ ⅝ ¾ 1 1³⁄₁₆	1³⁄₁₆	2	1¼	¾	½	..	3 7
9.0	9.3	½ ⅝ ¾ 1 1³⁄₁₆	1³⁄₁₆	2	1¼	¾	½	..	3 7
10.0	10.3	½ ⅝ ¾ 1 1³⁄₁₆	1³⁄₁₆	2	1¼	¾	½	..	4.3
11.0	11.3	¾ ⅞ ¹⁵⁄₁₆ 1 1³⁄₁₆ 1⁷⁄₁₆	1⁷⁄₁₆	2⅜	1¼	¾	½	..	5.5
12 0	12.3	¾ ⅞ ¹⁵⁄₁₆ 1 1³⁄₁₆ 1⁷⁄₁₆	1⁷⁄₁₆	2⅜	1¼	¾	½	..	6 5
14 0	14 3	¾ ⅞ ¹⁵⁄₁₆ 1 1³⁄₁₆ 1⁷⁄₁₆	1⁷⁄₁₆	2⅜	1¼	¾	½	..	7 7
15 0	15.3	¾ ⅞ ¹⁵⁄₁₆ 1 1³⁄₁₆ 1⁷⁄₁₆	1⁷⁄₁₆	2⅜	1¼	¾	½	..	9.0

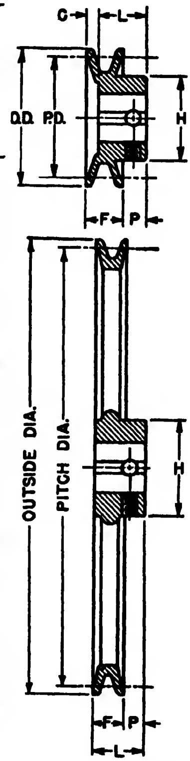


Fig. 5. (*Top*) cast-iron, light-duty V-belt sheaves of 3.7-inch pitch diameter and smaller. (*Bottom*) Same type of sheaves of 4-inch pitch diameter and larger. These are for No. 1,000 series belts.

TABLE 6. SIZE AND WEIGHT OF CAST-IRON LIGHT-DUTY SHEAVES FOR NO. 2,000 BELT

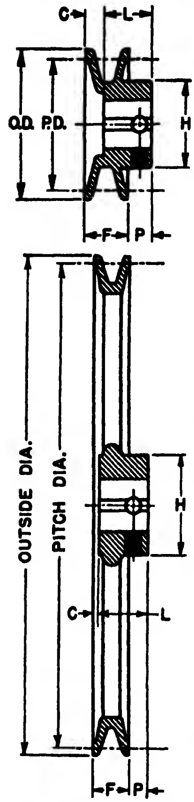


FIG. 6. (*Top*) cast-iron, light-duty V-belt sheaves of 3.9-inch pitch diameter and smaller. (*Bottom*) Same type of sheaves of 4.1-inch pitch diameter and larger. These are for No. 2,000 series belts.

Pitch diam. in., for No. 2,000 belt	*Outside diam., in.*	*Standard stock bores, in.*	*Max bore*	*Dimensions*					*Net wt., lb*
				H	*L*	*F*	*P*	*C*	
2.6	3.0	1/2 5/8 3/4 1	1	1 3/4	1	7/8	1/2	3/8	0.8
2.8	3.2	1/2 5/8 3/4 1	1	1 3/4	1	7/8	1/2	3/8	0.9
3.0	3.4	1/2 5/8 3/4 1	1	1 3/4	1	7/8	1/2	3/8	1.0
3.2	3.6	1/2 5/8 3/4 1	1	1 3/4	1	7/8	1/2	3/8	1.1
3.4	3.8	1/2 5/8 3/4 1	1	1 3/4	1	7/8	1/2	3/8	1.2
3.6	4.0	1/2 5/8 3/4 1	1	1 3/4	1	7/8	1/2	3/8	1.3
3.9	4.3	1/2 5/8 3/4 1	1	1 3/4	1	7/8	1/2	3/8	1.8
4.1	4.5	1/2 5/8 3/4 1	1	1 3/4	1 1/4	7/8	1/2	1/8	1.9
4.4	4.8	1/2 5/8 3/4 1	1	1 3/4	1 1/4	7/8	1/2	1/8	2.3
4.6	5.0	1/2 5/8 3/4 1	1	1 3/4	1 1/4	7/8	1/2	1/8	2.4
4.9	5.3	1/2 5/8 3/4 1	1	1 3/4	1 1/4	7/8	1/2	1/8	2.6
5.1	5.5	1/2 5/8 3/4 1	1	1 3/4	1 1/4	7/8	1/2	1/8	2.9
5.4	5.8	1/2 5/8 3/4 1	1	1 3/4	1 1/4	7/8	1/2	1/8	3.0
5.6	6.0	1/2 5/8 3/4 1	1	1 3/4	1 1/4	7/8	1/2	1/8	3.1
5.9	6.3	1/2 5/8 3/4 1 1 3/16	1 1/4	2	1 1/4	7/8	1/2	1/8	3.3
6.1	6.5	1/2 5/8 3/4 1 1 3/16	1 1/4	2	1 1/4	7/8	1/2	1/8	3.5
6.4	6.8	1/2 5/8 3/4 1 1 3/16	1 1/4	2	1 1/4	7/8	1/2	1/8	3.7
7.4	7.8	1/2 5/8 3/4 1 1 3/16	1 1/4	2	1 1/4	7/8	1/2	1/8	3.9
8.4	8.8	1/2 5/8 3/4 1 1 3/16	1 1/4	2	1 1/4	7/8	1/2	1/8	4.5
9.4	9.8	1/2 5/8 3/4 1 1 3/16	1 1/4	2	1 1/4	7/8	1/2	1/8	4.9
10.4	10.8	1/2 5/8 3/4 1 1 3/16	1 1/4	2	1 1/4	7/8	1/2	1/8	5.7
11.4	11.8	3/4 7/8 15/16 1 1 3/16 1 7/16	1 7/16	2 3/8	1 1/4	7/8	1/2	1/8	6.0
12.4	12.8	3/4 7/8 15/16 1 1 3/16 1 7/16	1 7/16	2 3/8	1 1/4	7/8	1/2	1/8	7.7
14.4	14.8	3/4 7/8 15/16 1 1 3/16 1 7/16	1 7/16	2 3/8	1 1/4	7/8	1/2	1/8	9.5
15.4	15.8	3/4 7/8 15/16 1 1 3/16 1 7/16	1 7/16	2 3/8	1 1/4	7/8	1/2	1/8	10.2

TABLE 7. DIMENSIONS AND WEIGHTS OF PRESSED-STEEL LIGHT-DUTY SHEAVES

Pitch diameter, in.		*Out-side diam., in.*	*Type*	*Standard stock bores, in.*	*Max. bore, in.*	*Net weight, lb*
For No. 1,000 belt	*For No. 2,000 belt*					
2 6		3 225	7	½ ⅝ ¾ 1	1	7
2 8		3 425	7	½ ⅝ ¾ 1	1	7
3 0		3 625	7	½ ⅝ ¾ 1	1	8
3 2		3 825	7	½ ⅝ ¾ 1	1	8
3 4		4 025	7	½ ⅝ ¾ 1	1	8
3 6		4 225	7	½ ⅝ ¾ 1	1	8
3 8		4 425	7	½ ⅝ ¾ 1	1	9
4 0		4 625	7	½ ⅝ ¾ 1	1	1 0
4 2	4 6	4.825	7	½ ⅝ ¾ 1	1	1 0
4 4	4 8	5.025	7	½ ⅝ ¾ 1	1	1 0
4 6	5 0	5 225	7	½ ⅝ ¾ 1	1	1 1
4 8	5 2	5 425	7	½ ⅝ ¾ 1	1	1 1
5 0	5 4	5 625	14	½ ⅝ ¾ 1	1	1 2
5 2	5 6	5.825	14	½ ⅝ ¾ 1	1	1 2
5 4	5 8	6.025	14	½ ⅝ ¾ 1	1	1 3
5 6	6 0	6 225	13	½ ⅝ ¾ 1 1 3/16	1¼	2 0
5 8	6 2	6 425	13	½ ⅝ ¾ 1 1 3/16	1¼	2 1
6 0	6 4	6 625	13	½ ⅝ ¾ 1 1 3/16	1¼	2 2
6 2	6 6	6 825	13	½ ⅝ ¾ 1 1 3/16	1¼	2 3
6 4	6.8	7.025	13	½ ⅝ ¾ 1 1 3/16	1¼	2 4
7 0	7 4	7 625	8	½ ⅝ ¾ 1 1 3/16	1¼	2 5
8 2	8 6	8 825	8	½ ⅝ ¾ 1 1 3/16	1¼	2 8
9 0	9 4	9 625	8	½ ⅝ ¾ 1 1 3/16	1¼	3 0
10 0	10.4	10 625	8	½ ⅝ ¾ 1 1 3/16	1¼	3 7
10 6	11 0	11 225	9 10	¾ ⅞ 15/16 1 1 3/16 1 7/16	1⅜ 2	5.2
12 0	12 4	12 625	9 10	¾ ⅞ 15/16 1 1 3/16 1 7/16	1⅜ 2	6.0
15 0	15 4	15 625	9 10	¾ ⅞ 15/16 1 1 3/16 1 7/16	1⅜ 2	7 7
18 0	18 4	18.625	9 10	¾ ⅞ 15/16 1 1 3/16 1 7/16	1⅜ 2	10 5

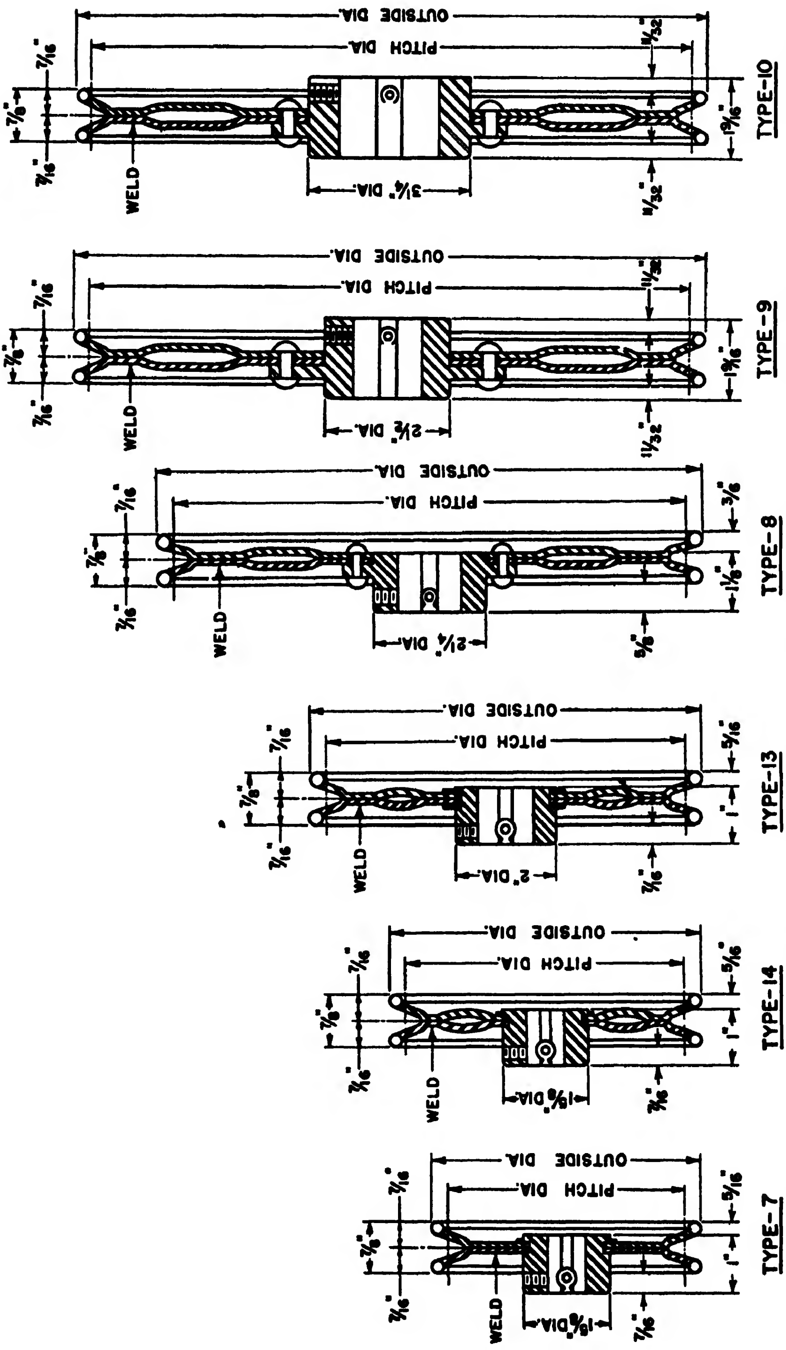


FIG. 7. Relative dimensions of pressed-steel, single-groove sheaves for light-duty V-belts. (See also Table 7 on page 83.)

TABLE 8. SHEAVE SETTINGS FOR NO. 1,000 BELTS ON ADJUSTABLE SHEAVES

No. turns from closed to open position	Pitch diameter, in.					
	2.0 to 3.0 in. P.D. sheave*	2.5 to 3.5 in. P.D. sheave	3.0 to 4.0 in. P.D. sheave*	3.5 to 4.5 in. P.D. sheave	4.0 to 5.0 in. P.D. sheave	4.5 to 5.5 in. P.D. sheave
0	3.000	3.500	4.000	4.500	5.000	5.500
½	2.930	3.428	3.930	4.428	4.930	5.428
1	2.858	3.358	3.858	4.358	4.858	5.358
1½	2.780	3.288	3.780	4.288	4.780	5.288
2	2.715	3.218	3.715	4.218	4.715	5.218
2½	2.630	3.148	3.630	4.148	4.630	5.148
3	2.572	3.078	3.572	4.078	4.572	5.078
3½	2.490	3.008	3.490	4.008	4.490	5.008
4	2.429	2.932	3.429	3.932	4.429	4.932
4½	2.350	2.862	3.350	3.862	4.350	4.862
5	2.286	2.790	3.286	3.790	4.286	4.790
5½	2.210	2.720	3.210	3.720	4.210	4.720
6	2.143	2.660	3.143	3.660	4.143	4.660
6½	2.070	2.570	3.070	3.570	4.070	4.570
7	2.000	2.500	3.000	3.500	4.000	4.500
Approx. speed range	50%	40%	33⅓%	28½%	25%	22%

* These columns cover 2- to 3- and 3- to 4-inch range of reversible sheave shown below.

PRESSED-STEEL SHEAVES. These are used on light-duty drives. Two pressed-steel halves are welded together to form groove and stiff web. A separate hub is riveted in place. The pitch diameters of stock cast-iron and pressed-steel sheaves vary slightly; so by using one sheave of each type, additional speed ratios are possible.

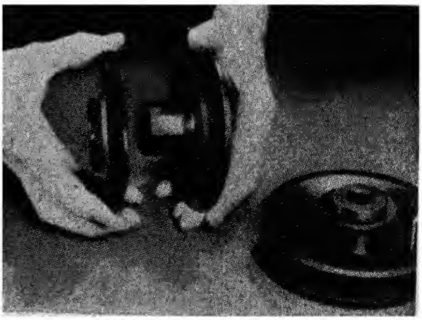


FIG. 8. An adjustable V-belt sheave is in two parts, one of which screws on the hub of the other like a nut on a bolt and is locked in position by a setscrew. By varying the distance between groove sides, a considerable range of pitch diameters, and therefore of speed ratios, is obtained.

ADJUSTABLE SHEAVES. These are in two parts, one of which threads on the hub of the other, like a nut. By regulating the number of turns and thus controlling the distance between sides of groove, the pitch diameter of the sheave is controlled.

Reversible Sheaves. This is a variation of the adjustable type, in which the movable half can be turned around to present a different groove-forming surface. Its pitch diameter range is about twice that of a nonreversible, adjustable sheave of similar size.

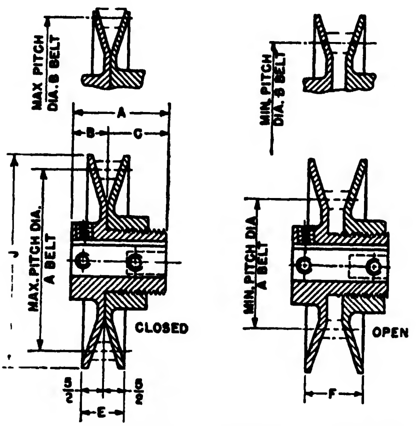


Fig. 9. Adjustable cast-iron sheaves.

Magic-grip Sheaves. The Allis-Chalmers and B. F. Goodrich Magic-grip sheaves slide easily on or off the drive shafts, yet lock tightly, with no chance of slipping. This type of sheave has a bushing assembly consisting of a tapered split sleeve, collar, and snap ring. By means of hollow-head cap screws, the split sleeve is caused to grip both the shaft and the bore of the sheave, the action being much like that of a lathe collet. The following outline of installing and removing a Magic-grip sheave will illustrate its advantages:

Installing. (1) With the bushing (sleeve) expanded, slip the sheave easily onto the shaft. (2) Line the sheave to the desired position. (3)

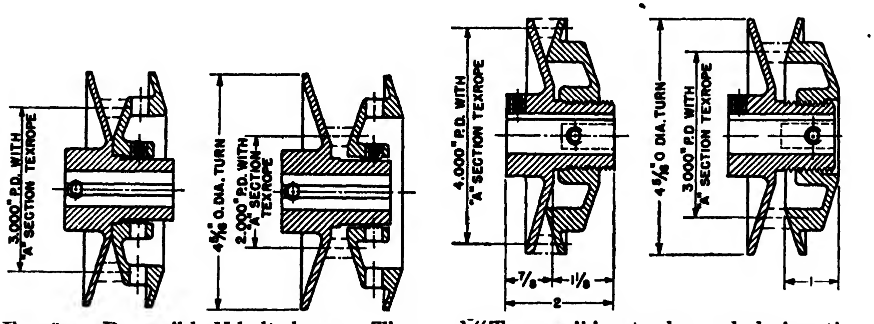


Fig. 9a. Reversible V-belt sheaves. The word "Texrope" is a trade-mark designation for Allis-Chalmers V-belts.

Tighten three hollow-head cap screws with a small wrench supplied with sheave.

Taking Off. (1) Remove the three cap screws, freeing the bushing collar. The sheave is still tight on the shaft. (2) Insert two of the screws into tapped holes in the collar; and using them as jackscrews, force the tapered, split bushing to release its grip. (3) Slide the sheave easily off the shaft.

Boltrim Sheaves. The B. F. Goodrich Boltrim sheave is in two parts. One is a hub that is bored to fit the shaft and is held in place by key and setscrews. The other section is a grooved sheave rim that is fastened to the hub with heat-treated cap screws. One hub will serve for several interchangeable rims of different sizes. Thus it is possible to alter speed ratios by changing sheave diameters without disturbing the sheave hubs.

Variable-pitch Sheaves. By means of suitable control devices, the pitch diameters of these sheaves can be changed while at rest or in motion. One or both halves of the sheave move relative to each other, to vary width of belt groove. Spring-held types can be varied by changing center-to-center distance between driver and driven shaft, as by moving motor with the aid of a crank screw.

Fig. 10. A reversible V-belt sheave is constructed like the adjustable type, but the movable part or plate is shaped so it can be turned around to present a different face to the belt, thus increasing speed (or pitch diameter) range. By reversing the plate shown, the sheave pitch diameter range of 2 to 3 inches is changed to a range of 3 to 4 inches.

Customer's Flywheel. When flat belt drives are to be replaced by V-belts, it is sometimes feasible for the flywheel on the machine to be grooved for multiple V-belts. The cost of doing this is usually about one-third the cost of a new V-belt sheave of corresponding size.

Open-end Belts

V-belting in long lengths, intended for use with fasteners, has a backbone of heavy cross-woven duck so that the metal fasteners can be anchored firmly to it. It is commonly supplied for industrial use in cross sections A to D, inclusive, as in Table 9.

Table 9

Section	*Top width, in.*	*Thickness, in.*	*Angle between sides, deg.*	*Lengths usually stocked, ft.*
A	$\frac{17}{32}$	$\frac{5}{16}$	40	100
B	$\frac{21}{32}$	$\frac{7}{16}$	40	500
C	$\frac{7}{8}$	$\frac{5}{8}$	40	500
D	$1\frac{1}{4}$	$\frac{3}{4}$	40	500

LIMITATIONS. The most efficient speed of open-end belts is under 3,000 feet per minute; the maximum safe speed, 4,000 feet per minute.

TABLE 10. MINIMUM PULLEY DIAMETERS

Section	*Inches*
A	3.0
B	5.4
C	9.0
D	13.0

Open-end V-belts preferably should be used only on V-V drives. They are not recommended for V-flat and quarter-turn drives.

PITCH LENGTH. Pitch length is the length of an open-end V-belt as measured when it is lying flat. Pitch (flat) length can be changed to outside or inside belt circumference by using Table 11.

TABLE 11

Belt section	*Outside circumference = pitch (flat) length plus, in.*	*Inside circumference = pitch length minus, in.*
A	1	1
B	1.33	1.33
C	2	2
D	2.33	2.33

OPEN-END V-BELT FASTENERS

Metal fasteners designed to join the ends of open-end V-belts hold so securely that the belt horsepower ratings are the same as for endless belts of comparative size at speeds below 4,000 feet per minute. Two types of fasteners are typical:

ALLIGATOR FASTENER. This fastener is made for *B*, *C*, and *D* section open-end V-belts. It consists of a steel end plate, bushing, two-piece rocker pin, links, and special nails. Special tools are available for installing

TABLE 12

Belt section	*Belt carefully watched; provisions for take-up. Subtract from each foot of belt length, in.*	*Belt not watched, no take-up. Subtract from each foot of belt length, in.*
B	1/16	3/32
C	3/32	5/32
D	1/8	3/16

and include a cutter for squaring belt ends, tool for punching nail holes, tool for inserting or extracting rocker pin, and a tightener for use where no belt take-up exists on drive.

Allowance must be made for tension when using Alligator fasteners, as shown in Table 12.

FLEX-V FASTENER. This is made only for *A* and *B* belts. It consists of two end plates, hinge pin, and mounting screws. There is no metal on inner belt circumference, thus permitting use on V-flat drives. Installation tools include a squaring cutter, jig or applicator, and screw driver.

Flex-V fasteners require no allowance for tension, since they are not intended for use with belts that are subjected to heavy tension loading.

ALLOWANCE FOR FASTENER LENGTH. Subtract the following from total belt length, to provide space for fastener:

TABLE 13

Belt section	*Alligator fastener, in.*	*Flex-V fastener, in.*
A	....	5/16
B	3/4	3/8
C	1	
D	1	

MISCELLANEOUS DATA

TABLE 14. PITCH LENGTH RELATIONS

Belt section	*Outside circumference = pitch length plus, in.*	*Inside circumference = pitch length minus, in.*
Light-duty V-belts:		
No. 1,000	0.9	0.9
No. 2,000	1.2	1.2
Multiple V-belts:		
A	1	1
B	1.4	1.4
C	1.7	1.7
D	2.4	2.4
E	2.7	2.7

CENTER DISTANCE RELATIONS. For most efficient operation, distance between centers of driver and driven sheaves (or shafts) should come within certain limits.

TABLE 15. CENTER DISTANCE RELATIONS

Nominal lengths, in.	Min. allowance below standard center distance for application of belts, in.					Min. allowance above standard center distance for stretch and wear, in.
	A	B	C	D	E	All sections
26– 38*	3/4	1				1
38– 60	3/4	1	1 1/2			1 1/2
60– 90	3/4	1 1/4	1 1/2			2
90–120	1	1 1/4	1 1/2			2 1/2
120–158	1	1 1/4	1 1/2	2		3
158–195	...	1 1/4	2	2	2 1/2	3 1/2
195–240	...	1 1/2	2	2	2 1/2	4
240–270	...	...	2	2 1/2	2 1/2	4 1/2
270–330	...	...	2	2 1/2	3	5
330–420	...	...	2	2 1/2	3	6
420 and over	...	...	...	3	3 1/2	1.5% of belt length

* In each group the range is to but not including the second length.

For light-duty V-belt drives, center distance should be 1 to 1 1/2 times the pitch diameter of the larger sheave. Moderate variation either way is permissible.

For multiple V-belt drives, the range is 1 to 2 times the larger sheave diameter.

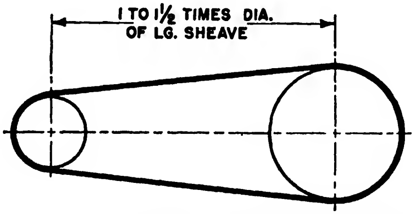


FIG. 11. This shows ideal center distance of light-duty V-belt drive, although somewhat greater or shorter distances are often used.

For V-flat drives, center distance should be about equal to diameter of large pulley.

For V-belt quarter-turn drives, center distance should be between 5.5 and 6 times the sum obtained by adding the diameter of the larger sheave to the width of the band of belts (see Table 31).

Determination of center distances between sheaves should include consideration of belt stretch and installation. That is, the centers should be arranged so they can be moved toward one another, so that belts can be installed or removed without stretching them over sheave rims, and

there should be provisions for moving the centers apart in order to offset belt and sheave wear and belt stretch. Table 15 shows the minimum allowances each way from standard center distances, for various nominal belt lengths, to permit installation without injuring the belt and to compensate for wear and stretch.

Speed Ratios. For V-V drives, the ratio may be from 1:1 to 7.50:1 for light-duty belts. For multiple V-belts, the ratio may run to 10:1 or higher.

For V-flat drives, the speed ratio should be 3:1 or greater.

For quarter-turn V-belt drives, the ratio should be no more than 2½:1. For a greater ratio, an auxiliary straight drive is usually recommended.

Selecting V-belt Drives

Standard V-belt drives should be selected with the aid of manufacturers' tables that show ratios, center distances, belt and sheave characteristics, etc. But for working out special V-belt drives or when suitable tables are not at hand, the following design procedure may be followed:

Step 1. In Table 16, find service factor for type of machine and power source.

Step 2. Determine design horsepower of drive by multiplying motor name-plate horsepower or brake horsepower of driven machine by service factor.

Step 3. Calculate speed ratio, which equals

$$\frac{\text{Rpm of high-speed shaft}}{\text{Rpm of low-speed shaft}}$$

If old drive was gear or chain, divide teeth on large gear or sprocket by teeth on small one. If flat belt drive, divide diameter of large pulley by that of smaller pulley.

Step 4. From Table 17, select belt section matching horsepower and motor speed.

Step 5. Find proper pitch diameter of small sheave with aid of Tables 18 and 19. Select as large a sheave as feasible, but keep belt speed below 5,000 feet per minute.

Step 6. Find proper pitch diameter (P.D.) of large sheave, by multiplying small-sheave pitch diameter by speed ratio.

When the product contains a fraction, take the next smaller whole number as the large-sheave pitch diameter. Divide this by the speed ratio to obtain the small-sheave pitch diameter. This manipulation reduces drive price slightly without appreciably reducing horsepower.

TABLE 16. SERVICE FACTORS

Driven machines	*Driving machines*	
	Electric motors *AC split phase* *AC normal torque squirrel cage and synchronous* *DC shunt wound* *Turbines, steam and water* *Water wheels* *Internal-combustion engines*	*Electric Motors* *AC single-phase series wound* *AC high torque or high slip* *AC slip ring* *AC repulsion-induction* *AC capacitor* *DC compound wound* *Steam engines* *Line shafts* *Clutch on driver or driven shaft*
Small fans to 10 hp. Centrifugal pumps Agitators for liquid Centrifugal compressors Package conveyors Blowers	1 1	1.2
Belt conveyors Line shafts Generators Punches, shears, and presses Revolving screens Fans Machine tools Printing machinery	1 2	1 4
Hammer mills Pulverizers Compressors Positive blowers Plunger pumps Screw conveyors Drag conveyors Saw mill machinery Textile machinery Bucket elevators Pug mills and brick machinery Paper mill beaters	1 4	1 6
Gyratory crushers Jaw crushers Roll crushers Cone crushers Ball mills Tube mills Rod mills Hoists	1 6	1 8

TABLE 17. GENERAL BELT-SELECTION TABLE

Horse-power	Motor speed, rpm						
	1,750	1,155	865	690	575	495	435
½-2	A	A	A				
3	A	A	B (or A)				
5	B (or A)	B (or A)	B				
7½	B	B	B				
10	B	B	B or C				
15	B	B or C	C or B				
20	B or C	C (or B)	C	D	D		
25	C (or B)	C	C	D	D		
30	C	C	C	D	D		
40	C	C or D	C or D	D	D		
50	C	C or D	C or D	D	D	E	E
60	C	C or D	D (or C)	D	D	E	E
75	C	D (or C)	D	D	D (or E)	E	E
100	C	D	D	D or E	E (or D)	E	E
125	......	D	D	D or E	E or D	E	E
150	.....	D	D	E (or D)	E	E	E
200 and above	...	D	D	E	E	E	E

When two cross sections are shown, use the smaller one if pulley diameters are limited, use the larger one if pulley face widths are limited; otherwise use the cross sections that provide the most economical drive.

Cross sections in parentheses may be used but are not ordinarily recommended.

TABLE 18. RANGE OF SMALL SHEAVE SIZES FOR VARIOUS MULTIPLE V-BELT CROSS SECTIONS*

Belt section	Recommended range of small sheave diam., in.	Absolute min. diam., in.
A	3.0– 5.0	2.6
B	5.4– 7.5	4.6
C	8.0–12.0	7.0
D	13.0–20.0	12.0
E	22.0–28.0	18.0

* Select for the small sheave a diameter within the range given in Table 18 that will not give a belt speed in excess of 5,000 fpm (as checked from Table 19).

When large-sheave pitch diameter is fixed or limited, divide it by the speed ratio to obtain small-sheave pitch diameter, and from Table 18 select proper belt section.

TABLE 19. SHEAVE SIZE FOR 5,000-FT BELT SPEED

Rpm of small sheave	*Sheave diam. for 5,000 fpm belt speed, in.*	*Rpm of small sheave*	*Sheave diam. for 5,000 fpm belt speed, in.*
6,361	3	1,060	18
4,771	4	1,004	19
3,817	5	954	20
3,181	6	867	22
2,726	7	795	24
2,385	8	734	26
3,120	9	681	28
1,908	10	596	32
1,735	11	530	36
1,590	12	477	40
1,468	13	434	44
1,363	14	397	48
1,272	15	367	52
1,193	16	341	56
1,122	17	318	60

Step 7. Determine center distance between sheaves. Usually this distance lies within 1 to 2 times diameter of larger sheave.

Select an arbitrary center distance within these limits or limitations of the installation, and solve for belt length by using the formula

$$L = 2C + 1.57(D + d) + \frac{(D - d)^2}{4C}$$

where L = belt pitch length
C = center distance in inches
D = large sheave pitch diameter in inches
d = small sheave pitch diameter in inches

Consult Table 28 or 33 showing standard V-belt lengths (pages 106, 116), and select belt length nearest that calculated.

Using this belt length (from the table) as the value for L in the following formula, solve for the corrected center distance:

$$C = \frac{L - 1.57(D + d) - \frac{(D - d)^2}{L}}{2}$$

TABLE 20a. HORSEPOWER RATINGS FOR A-SECTION V-BELTS

Speed, fpm	Pitch diameter, in.						
	2.6	3.0	3.4	3.8	4.2	4.6	5.0 and larger
1,000	0.54	0.67	0.78	0.86	0.93	0.99	1 03
1,100	0.59	0.74	0.85	0.95	1.02	1.08	1.13
1,200	0.63	0.80	0.93	1.03	1.11	1.18	1.23
1,300	0.68	0.86	1.00	1.11	1.20	1.27	1.33
1,400	0.73	0.92	1.07	1.19	1.28	1.36	1.43
1,500	0.78	0.98	1.14	1.27	1.37	1.45	1.52
1,600	0.82	1.04	1.21	1.34	1.45	1.54	1.62
1,700	0.86	1.10	1.28	1.42	1.54	1.63	1.71
1,800	0.90	1.15	1.34	1.50	1.62	1.72	1.80
1,900	0.94	1.21	1.41	1.57	1.70	1.80	1.89
2,000	0.98	1.26	1.47	1.64	1.77	1.89	1.98
2,100	1.02	1.31	1.53	1.71	1.85	1.97	2.07
2,200	1.05	1.36	1.59	1.78	1.93	2.05	2.15
2,300	1.09	1.41	1.65	1.84	2.00	2.13	2.23
2,400	1.12	1.45	1.70	1.91	2.07	2.20	2.31
2,500	1.15	1.49	1.76	1.97	2.14	2.28	2.39
2,600	1.17	1.53	1.81	2.03	2.20	2.35	2.47
2,700	1.20	1.57	1.86	2.08	2.27	2.42	2.54
2,800	1.22	1.61	1.90	2.14	2.33	2.48	2.62
2,900	1.24	1.64	1.95	2.19	2.39	2.55	2.68
3,000	1.26	1.67	1.99	2.24	2.44	2.61	2.75
3,100	1.27	1.70	2.03	2.29	2.50	2.67	2.82
3,200	1.28	1.72	2.06	2.33	2.55	2.73	2.88
3,300	1.29	1.75	2.10	2.37	2.60	2.78	2.94
3,400	1.30	1.77	2.13	2.41	2.64	2.83	2 99
3,500	1.30	1.78	2.15	2.45	2.68	2.88	3.04
3,600	1.30	1.80	2.18	2.48	2.72	2.92	3.09
3,700	1.29	1.81	2.20	2.51	2.76	2.97	3.14
3,800	1.29	1.81	2.22	2.53	2.79	3.01	3.18
3,900	1.28	1.82	2.23	2.56	2.82	3.04	3.22
4,000	1.26	1.82	2.24	2.58	2.85	3.07	3.26
4,100	1.25	1.82	2.25	2.59	2.87	3.10	3.29
4,200	1.23	1.81	2.25	2.61	2.89	3.13	3.32
4,300	1.20	1.80	2.25	2.61	2.91	3.15	3.35
4,400	1.18	1.78	2.25	2.62	2.92	3.16	3.37
4,500	1.14	1.77	2.24	2.62	2.93	3.18	3.39
4,600	1.11	1.75	2.23	2.62	2.93	3.19	3.40
4,700	1.07	1.72	2.22	2.61	2.93	3.19	3.41
4,800	1.02	1.69	2.20	2.60	2.92	3.19	3.42
4,900	0.98	1.66	2.17	2.58	2.92	3.19	3.42
5,000	0.92	1.62	2.15	2.56	2.90	3.18	3.42

TABLE 20b. HORSEPOWER RATINGS FOR B-SECTION V-BELTS

Speed, fpm	Pitch diameter, in.					
	5.0	5.4	5.8	6.2	6.6	7.0 and larger
1,000	1.25	1.37	1.47	1.55	1.63	1.69
1,100	1.37	1.50	1.61	1.70	1.78	1.86
1,200	1.49	1.63	1.74	1.85	1.94	2.02
1,300	1.60	1.75	1.88	1.99	2.09	2 18
1,400	1.72	1.88	2.02	2.14	2.24	2.34
1,500	1.83	2.00	2.15	2.28	2.39	2.49
1,600	1.94	2.12	2.28	2.42	2.54	2 65
1,700	2.05	2.24	2.41	2.56	2.68	2.80
1,800	2.15	2.36	2.54	2.69	2.83	2.95
1,900	2.25	2.47	2.66	2.82	2.97	3.09
2,000	2.35	2.58	2.78	2.95	3.10	3.24
2,100	2.45	2.69	2.90	3.08	3.24	3.38
2,200	2.54	2.79	3.01	3.20	3.37	3.51
2,300	2.63	2.89	3.12	3.32	3.49	3.65
2,400	2.72	2.99	3.23	3.44	3.62	3.78
2,500	2.80	3.09	3.33	3.55	3.74	3.90
2,600	2.88	3.18	3.43	3.66	3.85	4.03
2,700	2.95	3.26	3.53	3.76	3.96	4.15
2,800	3.02	3.34	3.62	3.86	4.07	4.26
2,900	3.09	3.42	3.71	3.96	4.18	4.37
3,000	3.15	3.50	3.79	4.05	4.28	4.48
3,100	3.21	3.57	3.87	4.14	4.37	4.58
3,200	3.26	3.63	3.95	4.22	4.46	4.68
3,300	3.31	3.69	4 02	4.30	4.55	4.77
3,400	3.36	3.74	4.08	4.37	4.63	4.86
3,500	3.39	3.79	4.14	4.44	4.70	4.94
3,600	3.43	3.84	4.19	4.50	4.77	5.02
3,700	3.45	3.88	4.24	4.56	4 84	5.09
3,800	3.48	3.91	4.29	4.61	4.90	5.15
3,900	3.49	3.94	4.32	4.66	4 95	5.21
4,000	3.50	3.96	4.35	4.70	5.00	5.27
4,100	3.51	3.97	4.38	4.73	5.04	5.32
4,200	3.50	3 98	4.40	4.76	5.08	5.36
4,300	3.50	3.99	4.41	4.78	5.11	5.39
4,400	3.48	3.98	4.42	4.80	5.13	5.42
4,500	3.46	3.97	4.42	4.80	5.14	5.45
4,600	3.43	3.96	4.41	4.81	5.15	5.46
4,700	3.40	3.93	4.40	4.80	5.16	5.47
4,800	3.35	3.90	4.38	4.79	5.15	5.47
4,900	3.30	3.86	4.35	4.77	5.14	5.47
5,000	3.25	3.82	4.31	4.74	5.12	5.45

TABLE 20c. HORSEPOWER RATINGS FOR C-SECTION V-BELTS

Speed, fpm	Pitch diameter, in.					
	7.0	8 0	9.0	10.0	11.0	12.0 and larger
1,000	1.99	2.47	2.85	3.15	3.39	3.59
1,100	2.18	2.71	3.12	3.45	3.72	3 95
1,200	2.37	2.94	3.39	3.75	4.05	4.29
1,300	2.55	3.18	3.66	4.05	4.37	4.64
1,400	2.73	3.41	3.93	4.35	4.69	4.98
1,500	2.91	3.63	4.19	4.64	5.01	5.32
1,600	3.08	3.85	4.45	4.93	5.33	5.65
1,700	3.25	4.07	4.71	5.22	5.64	5.98
1,800	3.42	4.29	4.96	5.50	5.94	6.31
1,900	3.58	4.50	5.21	5.78	6.24	6.63
2,000	3.74	4.70	5.45	6.05	6.54	6.95
2,100	3.89	4.90	5.69	6.32	6 84	7.26
2,200	4.04	5.10	5.92	6.58	7 12	7.57
2,300	4 18	5.29	6.15	6.84	7.41	7 88
2,400	4.32	5.48	6.38	7.09	7.68	8 17
2,500	4.45	5.66	6.59	7.34	7.96	8.47
2,600	4.58	5.83	6.80	7.58	8.22	8.75
2,700	4.70	6.00	7.01	7.82	8.48	9.03
2,800	4.81	6.16	7.21	8.05	8.73	9 30
2,900	4.92	6.31	7.40	8.27	8.98	9 57
3,000	5.02	6.46	7.58	8.48	9.22	9.83
3,100	5.11	6.60	7.76	8.69	9.45	10.1
3,200	5.19	6.73	7.93	8.89	9.68	10.3
3,300	5.27	6.86	8.09	9.08	9.89	10.6
3,400	5.34	6.98	8 25	9.27	10.1	10.8
3,500	5.40	7.09	8.40	9.45	10.3	11.0
3,600	5.45	7.19	8.53	9.61	10.5	11.2
3,700	5.50	7.28	8 66	9.77	10.7	11.4
3,800	5.53	7.36	8.79	9.92	10.9	11.6
3,900	5.56	7.44	8 90	10.1	11.0	11.8
4,000	5.58	7.50	9.00	10.2	11.2	12.0
4,100	5 58	7.56	9.09	10.3	11.3	12.2
4,200	5 58	7.60	9.18	10.4	11.5	12.3
4,300	5.57	7.64	9.25	10.5	11.6	12.5
4,400	5.55	7.66	9.31	10.6	11.7	12.6
4,500	5.51	7.68	9.37	10.7	11.8	12.7
4,600	5.47	7.68	9.41	10.8	11.9	12.9
4,700	5.41	7.68	9.44	10.8	12.0	13.0
4,800	5.35	7.66	9.46	10.9	12.1	13.1
4,900	5.27	7.63	9.47	10.9	12.1	13.1
5,000	5.18	7.59	9.46	11.0	12.2	13.2

TABLE 20d. HORSEPOWER RATINGS FOR D-SECTION V-BELTS

Speed, fpm	Pitch diameter, in.					
	12.0	13.0	14.0	15.0	16.0	17.0 and larger
1,000	4.46	5.09	5.62	6.08	6.48	6.84
1,100	4.89	5.58	6.16	6.67	7.11	7.51
1,200	5.31	6.06	6.70	7.25	7.74	8.17
1,300	5.73	6.54	7.23	7.83	8.36	8.82
1,400	6.14	7.01	7.76	8.40	8.97	9.47
1,500	6.54	7.48	8.28	8.97	9.57	10.1
1,600	6.94	7.93	8.79	9.53	10.2	10.7
1,700	7.33	8.38	9.29	10.1	10.8	11.4
1,800	7.71	8.83	9.78	10.6	11.3	12.0
1,900	8.08	9.26	10.3	11.1	11.9	12.6
2,000	8.44	9.68	10.7	11.7	12.5	13.2
2,100	8.79	10.1	11.2	12.2	13.0	13.8
2,200	9.13	10.5	11.7	12.7	13.6	14.4
2,300	9.46	10.9	12.1	13.2	14.1	14.9
2,400	9.78	11.3	12.6	13.7	14.6	15.5
2,500	10.1	11.6	13.0	14.1	15.1	16.0
2,600	10.4	12.0	13.4	14.6	15.6	16.6
2,700	10.7	12.3	13.8	15.0	16.1	17.1
2,800	10.9	12.7	14.2	15.5	16.6	17.6
2,900	11.2	13.0	14.5	15.9	17.1	18.1
3,000	11.4	13.3	14.9	16.3	17.5	18.6
3,100	11.7	13.6	15.2	16.7	17.9	19.0
3,200	11.9	13.9	15.6	17.0	18.3	19.5
3,300	12.1	14.1	15.9	17.4	18.7	19.9
3,400	12.3	14.4	16.2	17.7	19.1	20.3
3,500	12.4	14.6	16.5	18.1	19.5	20.7
3,600	12.6	14.8	16.7	18.4	19.8	21.1
3,700	12.7	15.0	17.0	18.7	20.2	21.5
3,800	12.8	15.2	17.2	18.9	20 5	21.8
3,900	12.9	15.3	17.4	19.2	20.8	22.2
4,000	13.0	15.5	17.6	19.4	21.0	22.5
4,100	13.0	15.6	17.8	19.6	21.3	22.8
4,200	13.1	15.7	17.9	19.8	21.5	23.0
4,300	13.1	15.7	18.0	20.0	21.8	23.3
4,400	13.1	15.8	18.1	20.2	21.9	23.5
4,500	13.0	15.8	18.2	20.3	22.1	23.7
4,600	13.0	15.8	18.3	20.4	22.3	23.9
4,700	12.9	15.8	18.3	20.5	22.4	24.1
4,800	12.8	15.8	18.3	20.6	22.5	24.2
4,900	12.7	15.7	18.3	20.6	22.6	24 3
5,000	12.5	15.6	18.3	20.6	22.6	24.4

TABLE 20e. HORSEPOWER RATINGS FOR *E*-SECTION V-BELTS

Speed, fpm	Pitch diameter, in.								
	20.0	21.0	22.0	23.0	24.0	25.0	26.0	27.0	28.0 and larger
1,000	7.96	8.49	8.98	9.42	9.82	10.2	10.5	10 9	11.1
1,100	8.73	9.31	9.85	10.3	10.8	11.2	11.6	11.9	12.2
1,200	9.49	10.1	10.7	11.2	11.7	12.2	12.6	13.0	13.3
1,300	10.2	10.9	11.6	12.1	12.7	13.1	13.6	14.0	14.4
1,400	11.0	11.7	12.4	13.0	13.6	14.1	14.6	15.0	15.4
1,500	11.7	12.5	13.2	13.9	14.5	15.1	15.6	16.0	16.5
1,600	12.4	13.3	14.1	14.8	15.4	16.0	16.6	17.1	17.5
1,700	13.1	14.0	14.9	15.6	16.3	16.9	17.5	18.1	18.6
1,800	13.8	14.8	15.7	16.5	17.2	17.9	18.5	19.0	19.6
1,900	14.5	15.5	16.4	17 3	18.0	18 8	19.4	20.0	20.6
2,000	15.2	16.2	17.2	18.1	18.9	19.6	20.3	21.0	21.6
2,100	15.8	17.0	18.0	18.9	19.7	20.5	21.2	21.9	22.5
2,200	16.5	17.6	18.7	19 7	20.6	21 4	22.1	22.8	23.5
2,300	17.1	18.3	19.4	20 4	21.4	22 2	23.0	23.7	24.4
2,400	17.7	19.0	20.1	21.2	22.2	23.1	23.9	24.6	25.3
2,500	18.3	19.6	20.8	21.9	22.9	23.9	24.7	25.5	26.3
2,600	18.9	20.2	21.5	22.6	23.7	24.7	25.5	26.4	27.1
2,700	19.4	20.8	22.1	23.3	24.4	25.4	26.4	27.2	28.0
2,800	19.9	21.4	22.8	24.0	25.1	26.2	27.1	28.0	28.9
2,900	20.4	22.0	23.4	24.7	25.8	26.9	27.9	28.8	29.7
3,000	20.9	22.5	24.0	25.3	26.5	27.6	28.6	29.6	30.5
3,100	21 4	23.0	24.5	25.9	27.2	28.3	29.4	30.4	31.3
3,200	21.8	23.5	25.1	26.5	27.8	29.0	30.1	31.1	32.0
3,300	22.3	24.0	25.6	27.1	28.4	29.6	30.7	31.8	32 8
3,400	22.6	24.5	26.1	27.6	29.0	30.2	31.4	32.5	33.5
3,500	23.0	24.9	26.6	28.1	29.5	30.8	32.0	33.1	34.2
3,600	23.4	25.3	27.0	28.6	30.0	31.4	32.6	33 8	34.8
3,700	23.7	25.6	27.4	29.1	30.5	31.9	33.2	34.4	35.5
3,800	24.0	26.0	27.8	29 5	31.0	32.4	33.7	34.9	36.1
3,900	24 2	26.3	28.2	29.9	31.5	32.9	34.3	35.5	36.6
4,000	24.5	26.6	28.5	30.3	31.9	33.4	34.7	36.0	37.2
4,100	24.7	26.8	28.8	30.6	32.3	33.8	35.2	36.5	37.7
4,200	24.8	27.1	29.1	30.9	32.6	34.2	35.6	37.0	38.2
4,300	25.0	27.2	29.3	31.2	33.0	34.6	36.0	37.4	38.7
4,400	25.1	27.4	29.5	31.5	33 3	34.9	36.4	37.8	39.1
4,500	25.2	27.5	29.7	31.7	33.5	35.2	36.7	38.2	39.5
4,600	25.2	27.6	29.9	31 9	33.7	35.5	37.0	38.5	39.9
4,700	25 2	27.7	30 0	32.0	33.9	35.7	37 3	38 8	40.2
4,800	25 2	27 7	30 0	32.2	34.1	35 9	37.5	39.1	40 5
4,900	25.1	27.7	30 1	32 2	34.2	36.0	37.7	39 3	40.7
5,000	25.0	27.7	30.1	32.3	34.3	36 2	37 9	39.5	40.9

where the letters have the same significance as in the preceding belt pitch length formula.

Step 8. Determine horsepower per belt:

a. Calculate belt speed with aid of the formula:

$$\text{Belt speed, fpm} = \text{P.D. of driving sheave, in.} \times \text{rpm} \times 0.262$$

b. From Table 20, find horsepower per belt corresponding to driving sheave diameter and belt speed found in (*a*). This is horsepower for 180-degree arc of contact between belt and sheave.

c. Determine corrected arc of contact for small sheave with aid of formula:

$$\text{Arc of contact, deg.} = 180 - \frac{60(D - d)}{C}$$

where D = pitch diameter of large sheave
d = pitch diameter of small sheave
C = center distance between sheaves

TABLE 21. CORRECTION FACTORS CORRESPONDING TO VARIOUS DEGREES OF CONTACT ON SMALL SHEAVE

Arc of contact, deg	*Correction factor*	*Arc of contact, deg*	*Correction factor*
180	1.00	130	0.86
170	0 98	120	0.83
160	0 95	110	0 79
150	0 92	100	0.74
140	0 89	90	0 69

From Table 21, select the correction factor for the arc of contact just calculated.

d. Determine corrected horsepower per belt by multiplying horsepower found in *b* by correction factor determined in *c*.

Step 9. Calculate number of V-belts required by dividing design horsepower (found in Step 2) by corrected horsepower per belt (Step 8). If the answer contains a fraction, use the next higher whole number.

The foregoing procedure has provided the correct belt section, sheave sizes, sheave center distance, belt length, and number of V-belts required.

EXACT SPEED CORRECTIONS

V-belt sheaves are normally listed according to their nominal pitch diameters. Ordinarily, the use of these diameters will give close enough

values for the speed of the driven sheave. However, when very exact control of machine speed is desired, corrections should be made using Table 22 as a guide.

TABLE 22. CORRECTION FACTORS

	V-belt section				
	A	*B*	*C*	*D*	*E*
V-sheave factor	0.17	0.22	0.28	0.38	0.43
Flat-pulley factor	0.44	0.66	0.80	1.14	1.28

Step 1. To the nominal pitch diameter of the large sheave, add the proper V-sheave factor from Table 22. If a flat pulley is used, add the flat-pulley factor instead. This gives the actual pitch diameter.

Step 2. Divide this actual pitch diameter by the speed ratio of the drive. The answer is the actual pitch diameter of the small sheave.

Step 3. From this actual small sheave pitch diameter, subtract the proper V-sheave factor, as given in Table 22, to obtain nominal pitch diameter.

Step 4. If the small sheave is the driver, multiply the value found in Step 3 by 100.5. If the small sheave is driven, multiply by 99.5. Use this corrected nominal pitch diameter when ordering small sheave.

Flywheel Effect of Standard Multiple V-belt Sheave

To determine WR^2

where W = weight of rim in pounds

R = mean radius in feet = $r/12$, where r is radius in inches

Step 1. Consult the accompanying rim-weight chart, and determine the sheave rim weight in pounds per inch of width for the particular V-belt section and sheave pitch diameter involved.

Step 2. Multiply this weight by the width of the sheave rim in inches to obtain the value for W.

Step 3. Divide the pitch diameter by 2 to obtain pitch radius, and refer to Table 23 to find the amount that must be subtracted from this pitch radius to give the mean radius of sheave.

Step 4. Square the mean radius, and multiply it by the value of W as found in Step 2.

If these calculations show a flywheel effect that is too low, it will be necessary to increase the thickness of the sheave rim or add extra

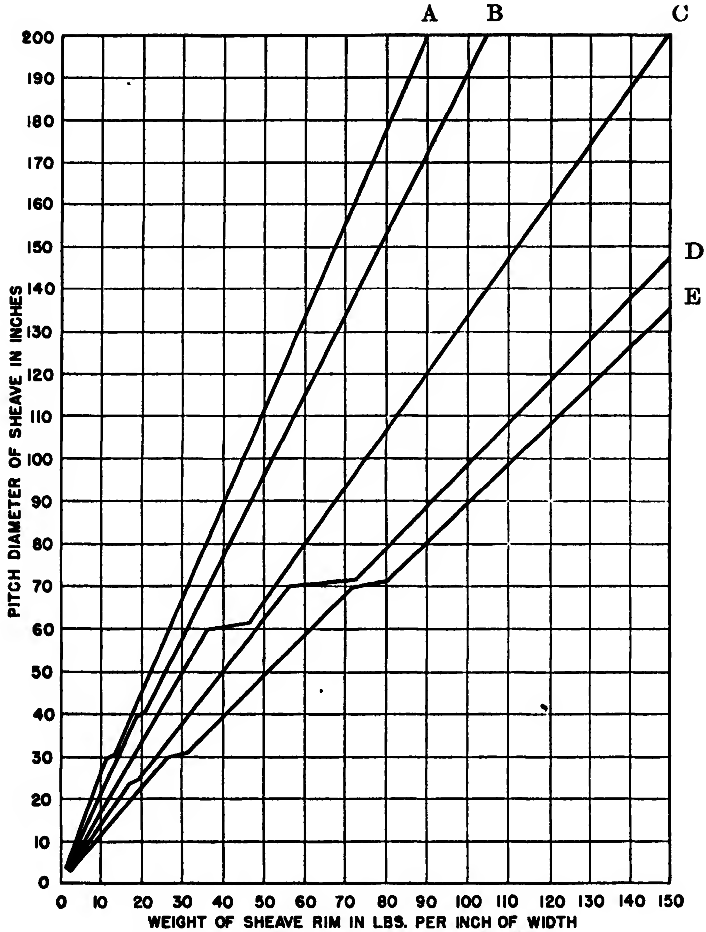


FIG. 12. Rim weight chart for use in calculating flywheel effect for multiple V-belt sheaves up to 12 grooves. Letters refer to belt sections.

TABLE 23. SHEAVE DIMENSIONS FOR CALCULATING FLYWHEEL EFFECT

Section	*Size of multiple V-belt, in.*	*To find mean radius of sheave subtract from pitch radius, in.*	*To find I.D. of sheave subtract from pitch diam., in.*
A	17/32 by 5/16	0.312 = 5/16	1.125 = 1 1/8
B	21/32 by 27/64	0.406 = 13/32	1.375 = 1 3/8
C	29/32 by 17/32	0 531 = 17/32	1.750 = 1 3/4
D	1 9/32 by 3/4	0.687 = 11/16	2.250 = 2 1/4
E	1 9/16 by 27/32	0.843 = 27/32	2.750 = 2 3/4

TABLE 24. LIGHT-DUTY V-BELT HORSEPOWER RATINGS BASED ON 180-DEG ARC OF CONTACT AND RPM OF DRIVER SHEAVE FOR 1,000-SECTION BELTS

Velocity, rpm	*Pitch diameters, in.*										
	2.0	*2.2*	*2.4*	*2.6*	*2.8*	*3.0*	*3.4*	*3.8*	*4.2*	*4.6*	*5.0*
3,450	0.38	0.55	0.74	0.92	1.08	1.22	1.53	1.77	1.99	2.16	2 31
3,000	0.35	0.50	0.67	0.83	0.98	1.13	1.42	1.68	1.90	2.14	2 30
2,875	0.34	0.49	0.65	0.81	0.95	1.10	1.38	1.64	1.85	2.12	2 27
2,400	0.30	0.42	0.57	0.70	0.82	0.95	1.21	1.46	1.66	1.99	2.08
1,800	0.23	0.33	0.43	0.54	0.65	0.74	0.94	1.15	1.32	1.52	1.75
1,725	0.22	0.32	0.41	0.52	0.62	0.71	0.91	1.11	1.28	1.47	1.70
1,500	....	....	....	0.46	0.55	0.62	0.82	1.02	1.13	1.31	1.47
1,440	....	....	....	....	0.53	0.61	0.77	0.93	1.08	1.26	1.41
1,200	....	....	....	....	....	....	0.67	0.80	0.93	1.07	1.20
1,150	....	....	....	....	....	....	0.64	0.77	0.89	1.03	1.16
1,000	....	....	....	....	....	....	....	0.68	0.78	0.90	1.02
860	....	....	....	....	....	....	....	....	....	0.77	0.90
800	....	....	....	....	....	....	....	....	....	....	0 83

TABLE 25. BELT HORSEPOWER RATINGS BASED ON 180-DEG ARC OF CONTACT AND RPM OF DRIVER SHEAVE FOR 2,000-SECTION BELTS

Velocity, rpm	*Pitch diameters, in.*																	
	2.6	*2.8*	*3.0*	*3 2*	*3 4*	*3.6*	*3.8*	*4 0*	*4 2*	*4 4*	*4 6*	*4.8*	*5.0*	*5 4*	*5 8*	*6 2*	*6 6*	*7 0*
3,450	0 20	0.49	0 78	1.06	1.34	1.60	1.83	2 08	2 31	2 52	2 66	2 83	2 98	3 27	3 45	3 68	3 77	
3,000	0 24	0 50	0 77	1.03	1.29	1.55	1 78	2 01	2 27	2 48	2.65	2 83	3 00	3 35	3 61	3 81	3 97	4 17
2,875	0 24	0 50	0.75	1.01	1.27	1.52	1.75	1 98	2 22	2 44	2.61	2 80	2 97	3.31	3 61	3 82	4 00	4 21
2,400	0 24	0.47	0.72	0.92	1.15	1.37	1.60	1 79	2.03	2 21	2.41	2.74	2.75	3.12	3.47	3.77	3 97	4 22
1,800	0 22	0 40	0 57	0.76	0.92	1.10	1.30	1.45	1 65	1.75	1.95	2 13	2.28	2.60	2 94	3 22	3 50	3 77
1,725	0 21	0 38	0.54	0 72	0 89	1.06	1.28	1.39	1 59	1.72	1 79	2 04	2.21	2.52	2.82	3.12	3 45	3.56
1,500	0.19	0 34	0 47	0 64	0 79	0 94	1.11	1.24	1.34	1.53	1 67	1 82	1.98	2.23	2.53	2 80	3 08	3 33
1,440	....	0 32	0 46	0.62	0.76	0.90	1.07	1.20	1.34	1.47	1.63	1.77	1.91	2.16	2.45	2 71	2 98	3.20
1,200	....	....	....	0.52	0.64	0 77	0.90	1.00	1.14	1.25	1.46	1.49	1 62	1 84	2 08	2 33	2 56	2 78
1,150	....	....	....	....	0.62	0.72	0 87	0.97	1.08	1.21	1.30	1.44	1 57	1.76	2 01	2 25	2 48	2 69
1,000	....	....	....	....	....	....	0.76	0.86	0 96	1.06	1.17	1.26	1.37	1.55	1 77	1 99	2 18	2 39
860	....	....	....	....	....	....	....		.	....	1 02	1 12	1 21	1 34	1 55	1.72	1 90	2 05
800	....	....	....	....	....	....	....	..	..	....	....	1 04	1.12	1 25	1.45	1 61	1.76	1 93
600	....	....	....	....	....	....	....	...	..	....	....	....	....	....	....	...	1 36	1 48

TABLE 26. LIGHT-DUTY V-BELT HORSEPOWER RATINGS BASED ON BELT VELOCITY IN FPM AND 180-DEG ARC OF CONTACT FOR 1,000-SECTION BELTS

Belt velocity, fpm = sheave pitch diameter, in. × rpm × 0.262

Velocity, fpm	*Pitch diameters, in.*										
	2.0	*2.2*	*2.4*	*2.6*	*2.8*	*3.0*	*3.4*	*3.8*	*4.2*	*4 6*	*5.0*
1,000	0.24	0.32	0.40	0.45	0.50	0.54	0.62	0.68	0.72	0 76	0.80
1,100	0.26	0.35	0.42	0.49	0.55	0.59	0.68	0.74	0.78	0.83	0.87
1,200	0.29	0.38	0.46	0.53	0.60	0.64	0.74	0.80	0.85	0.90	0.94
1,300	0.31	0.41	0.49	0.57	0.64	0.68	0.79	0.85	0.91	0.96	1.01
1,400	0.33	0.43	0.52	0.61	0.68	0.74	0.84	0.91	0.97	1.04	1.08
1,500	0.34	0.46	0.56	0.65	0.72	0.78	0.89	0.97	1.03	1.10	1.15
1,600	0.36	0.48	0.59	0.69	0.76	0.82	0.94	1.03	1.10	1.18	1 22
1,700	0.37	0.50	0.62	0.72	0.80	0.87	0.99	1.09	1.16	1.24	1.29
1,800	0.38	0.52	0.65	0.76	0.84	0.92	1.04	1.15	1.22	1.30	1 36
1,900	0.39	0.53	0.68	0.79	0.88	0.96	1.09	1.20	1.28	1.36	1.42
2,000	0.40	0.55	0.70	0.82	0.92	1.00	1.14	1.26	1.34	1.43	1 49
2,100	0.40	0.57	0.73	0.85	0.95	1.04	1.19	1.31	1.39	1.49	1 55
2,200	0.40	0.58	0.75	0.88	0.98	1.08	1.23	1.36	1.44	1.55	1 60
2,300	0.40	0.60	0.77	0.91	1.01	1.11	1.27	1.41	1.50	1.60	1 69
2,400	0.40	0.61	0.79	0.93	1.04	1.14	1.32	1.46	1.54	1.65	1.72
2,500	0.40	0.62	0.80	0.95	1.07	1.18	1.36	1.50	1.59	1.71	1.78
2,600	0.40	0.63	0.81	0.97	1.09	1.20	1.40	1.55	1.64	1.76	1.83
2,700	0.40	0.64	0.82	0.98	1.11	1.22	1.43	1.58	1.68	1.81	1 88
2,800	0.39	0.64	0.83	0.99	1.13	1.24	1.46	1.62	1.72	1.86	1 93
2,900	0.38	0.64	0.83	1.00	1.15	1.26	1.49	1.65	1.76	1.90	1 98
3,000	0.37	0.64	0.83	1.00	1.16	1.28	1.51	1.68	1.80	1.98	2.02
3,100	0.36	0.63	0.83	1.00	1.16	1.30	1.54	1.70	1.84	2.01	2.06
3,200	0.34	0.62	0.82	1.00	1.17	1.31	1.56	1.73	1.86	2.05	2.10
3,300	....	0.61	0.82	1.00	1.18	1.32	1.58	1.75	1.90	2.08	2.14
3,400	....	0.60	0.81	1.00	1.17	1.33	1.59	1.77	1.92	2.10	2.18
3,500	....	0.58	0.80	0.99	1.17	1.34	1.60	1.79	1.94	2.13	2.21
3,600	....	....	0.79	0.98	1.16	1.34	1.61	1.80	1.96	2.14	2.24
3,700	....	....	0.77	0.97	1.15	1.34	1.61	1.81	1.98	2.16	2.26
3,800	....	....	0.76	0.96	1.14	1.34	1.62	1.82	1.99	2.17	2.28
3,900	....	....	....	0.95	1.12	1.34	1.61	1.82	2.00	2.17	2.30
4,000	....	....	....	0.93	1.10	1.33	1.60	1.82	2.00	2.17	2.31
4,100	....	....	....	0.91	1.08	1.32	1.59	1.82	2.00	2.17	2.32
4,200	....	....	....	....	1.06	1.31	1.58	1.81	2.00	2.16	2.32
4,300	....	....	....	....	1.03	1.29	1.56	1.80	1.99	2.15	2.32
4,400	....	....	....	....	1.00	1.27	1.54	1.79	1.98	2.14	2.32
4,500	....	....	....	....	0.97	1.25	1.52	1.78	1.97	2.12	2.31
4,600	....	....	....	....	....	1.22	1.49	1.76	1.95	2.10	2.30
4,700	....	....	....	....	....	1.18	1.46	1.74	1.94	2.08	2.28
4,800	....	....	....	....	....	1.14	1.43	1.72	1.91	2.06	2.26
4,900	....	....	....	..	....	....	1 39	1.68	1.88	2.04	2.24
5,000	. ..	.	.	...	...	.	1.35	1.64	1.85	2 02	2.20

Table 27. Belt Horsepower Ratings Based on Belt Velocity in FPM and 180-deg Arc of Contact for 2,000-section Belts

Belt velocity, fpm = sheave pitch diameter, in. × rpm × 0.262

Velocity, fpm	*Pitch diameters, in.*																	
	2.6	*2.8*	*3.0*	*3.2*	*3.4*	*3.6*	*3.8*	*4.0*	*4.2*	*4 4*	*4.6*	*4.8*	*5.0*	*5.4*	*5.8*	*6.2*	*6.6*	*7.0*
1,000	0.18	0.31	0.42	0.52	0.61	0.68	0.76	0.83	0 89	0.94	0.99	1.04	1.08	1.13	1 21	1.26	1 31	1 36
1,100	0 20	0.34	0.45	0.57	0.66	0.75	0.83	0.90	0.96	1 02	1.07	1.12	1.17	1.22	1 32	1 38	1 42	1.48
1,200	0 21	0.36	0.49	0.62	0.72	0.81	0.90	0.97	1.04	1.10	1.16	1.21	1.27	1.33	1 43	1.50	1.55	1.60
1,300	0.22	0.39	0.53	0.66	0.77	0.87	0.97	1.04	1.12	1.19	1.25	1.31	1.36	1.44	1.54	1.61	1.67	1.73
1,400	0.23	0.41	0.56	0.70	0.82	0.93	1.04	1.12	1.20	1.27	1.34	1.40	1.46	1.54	1.64	1.72	1.79	1 86
1,500	0.24	0.43	0.60	0.75	0.87	0.99	1.11	1.19	1.28	1.35	1.42	1.49	1.56	1.64	1.75	1.84	1 91	1.98
1,600	0.24	0.45	0.62	0.79	0.92	1.04	1.18	1.26	1.36	1.43	1.50	1.58	1.64	1.74	1.86	1.96	2 02	2.10
1,700	0.25	0.46	0.65	0.82	0.96	1.10	1.24	1.32	1.43	1.51	1.59	1.66	1.74	1.84	1.96	2.06	2.14	2.22
1,800	0.25	0.48	0.68	0.86	1.01	1.16	1.30	1.39	1.50	1.59	1.67	1.76	1.83	1.93	2.06	2.18	2 26	2.34
1,900	0 24	0 49	0.70	0.89	1.06	1.21	1.36	1.46	1.57	1.66	1.75	1.84	1.92	2.02	2.16	2.28	2 37	2.46
2,000	0 24	0 50	0.72	0.92	1.10	1.26	1.42	1.52	1.64	1.74	1.83	1.93	2.01	2.12	2.26	2.38	2 48	2.58
2,100	0.23	0.50	0.74	0.95	1.14	1.31	1.47	1.58	1.70	1.82	1.91	2.00	2.10	2.21	2.36	2.48	2.58	2.68
2,200	0 22	0.50	0.75	0.97	1.17	1.35	1.52	1.64	1.77	1.89	1.99	2.09	2.17	2.30	2.46	2.58	2.68	2.78
2,300	0 21	0 50	0.76	0 99	1.20	1.39	1.56	1.69	1.83	1.96	2.06	2.16	2.24	2.39	2.55	2.67	2.79	2 88
2,400	0 20	0 50	0 77	1.01	1.23	1 42	1.60	1.74	1.89	2.01	2.12	2.24	2.32	2.48	2 64	2 77	2 89	2.98
2,500	0.18	0.50	0.77	1.03	1.26	1.46	1.64	1.79	1.94	2.07	2.19	2.30	2.39	2.56	2.73	2.86	2.98	3.08
2,600	0.16	0.49	0.78	1.04	1 28	1.49	1.68	1.83	1.99	2.12	2.25	2.37	2.44	2.64	2.81	2.94	3 08	3.18
2,700	0 14	0.48	0 78	1.05	1.30	1.52	1.71	1.87	2.03	2.18	2.30	2.42	2.50	2.72	2.90	3.03	3.18	3.27
2,800	0.10	0 47	0.78	1 06	1.32	1.54	1.74	1.91	2 08	2 23	2.36	2 48	2.56	2.79	2 98	3.12	3 26	3 36
2,900	0.07	0.45	0.77	1.06	1.33	1.56	1.76	1.94	2.12	2.28	2.41	2.53	2.62	2.85	3.05	3.20	3 35	3 46
3,000	0.02	0 44	0.76	1 07	1.34	1 58	1.78	1.98	2 16	2.32	2.46	2 58	2 68	2.92	3.12	3 28	3.44	3 55
3,100	....	0 42	0.75	1.06	1 34	1.59	1.80	2.00	2 19	2 36	2 50	2 62	2.72	2 98	3.18	3 35	3 50	3 62
3,200	...	0.39	0.73	1.06	1.34	1.60	1.81	2.02	2 22	2 40	2 54	2 66	2.77	3.03	3.24	3.42	3 58	3 70
3,300	....	0.35	0 71	1.05	1.34	1.60	1.82	2.04	2.25	2.44	2.58	2.70	2.81	3.08	3.30	3.48	3 64	3.77
3,400	....	0.32	0.69	1 03	1.33	1.60	1.83	2.06	2 27	2 47	2.60	2.74	2.86	3.12	3.36	3.54	3 70	3 84
3,500	....	0.27	0.66	1.01	1 32	1.60	1.84	2.07	2 29	2 49	2 63	2.77	2.89	3.17	3.40	3.59	3 76	3 90
3,600	....	0.21	0.6[illegible]	0.99	1.31	1.60	1.84	2.08	2 30	2 51	2 65	2.80	2.92	3.20	3.45	3 63	3.81	3.96
3,700	....	0.15	0.59	0.96	1.29	1.59	1.84	2.08	2.31	2.52	2.67	2.82	2.96	3.24	3.49	3.68	3.85	4.00
3,800	....	0.07	0.54	0.93	1.27	1.57	1.82	2.08	2.32	2.53	2.68	2.84	2.98	3.27	3.52	3.72	3 89	4.06
3,900	....	....	0.49	0.89	1.24	1.55	1.81	2.07	2 32	2.53	2 68	2 86	3.00	3.30	3.55	3.77	3 92	4.10
4,000	....	....	0.43	0.84	1.21	1.52	1.79	2.06	2.31	2.52	2.68	2 86	3.01	3.32	3.57	3.80	3.96	4.14
4,100	....	....	0.36	0.80	1.17	1.48	1.76	2.04	2.29	2.51	2.67	2.86	3.02	3.34	3.59	3.81	3.98	4.16
4,200	....	....	0.29	0.75	1.12	1.44	1.72	2.01	2.26	2.50	2.66	2.86	3.02	3.35	3.60	3.82	4.00	4.18
4,300	....	....	0.20	0.69	1.07	1.39	1.69	1.99	2.24	2.47	2 64	2 84	3.01	3.35	3.61	3.82	4.01	4.20
4,400	....	....	0.10	0.63	1.01	1.34	1.64	1.95	2.21	2.44	2.62	2.83	3.00	3.35	3.62	3.83	4.02	4.22
4,500	....	....	....	0.57	0.96	1.29	1.60	1.91	2.17	2.41	2.60	2.81	2.98	3.34	3.62	3.82	4.03	4.23
4,600	....	....	....	0 50	0.89	1.24	1.55	1.87	2.14	2.38	2.57	2.79	2.96	3.33	3.61	3 82	4 03	4.24
4,700	.	....	....	0 42	0 82	1.18	1.50	1 82	2 09	2 34	2 54	2 76	2.94	3.31	3 60	3.82	4 02	4.25
4,800	....	....	....	0.36	0.76	1.12	1 44	1 78	2.05	2 30	2 50	2 73	2 91	3.29	3.59	3 82	4 02	4.25
4,900	....	...	...	0.28	0.67	1 04	1 38	1 72	2 00	2.25	2.46	2 70	2 88	3.26	3.57	3 81	4 01	4.25
5,000	...	...	....	0 19	0.58	0 97	1 31	1.66	1 95	2.20	2.42	2.66	2 85	3.22	3 54	3.80	4.00	4 24

TABLE 28. LIGHT-DUTY V-BELT CONVERSION CHART
Standard No. 0000 (*"0"-section*)
$^3/_8$ in. top width × $^7/_{32}$ in. thickness × 40-deg angle.

Allis-Chalmers Diamond B. F. Goodrich Pyott Thermoid T. B. Woods Belt No.	*Outside length, in.*	*Browning*	*Dayton*	*Gates*	*Gilmer*	*Goodyear*	*Manhattan*
0110	11	FHP 0095	......	....	....	FO11	0095
0130	13	FHP 0115	......	1130	....	FO13	0115
0150	15	FHP 0135	0M015	....	....	FO15	0135
0170	17	FHP 0155	0M017	1170	2170	FO17	0155
0180	18	FHP 0165	0M018	....	2180	FO18	0165
0190	19	FHP 0175	0M019	1190	2190	FO19	0175
0200	20	FHP 0185	0M020	1200	2200	FO20	0185
0210	21	FHP 0195	0M021	1210	2210	FO21	0195
0220	22	FHP 0205	0M022	1220	2220	FO22	0205
0230	23	FHP 0215	0M023	1230	2230	FO23	0215
0240	24	FHP 0226	0M024	1240	2240	FO24	0225
0250	25	FHP 0235	0M025	1250	2250	FO25	0235
0255	25.5	FHP 0245	......	1255	2255	FO25½	0245
0260	26	.... . .	0M026	1260	2260	FO26	
0270	27	FHP 0255	0M027	1270	2270	FO27	0255
0280	28	FHP 0265	0M028	1280	2280	FO28	0265
0285	28.5	....	. .....	1285	2285	FO28½	
0290	29	FHP 0275	0M029	1290	2290	FO29	0275
0300	30	FHP 0285	0M030	1300	2300	FO30	0285
0310	31	FHP 0295	0M031	1310	2310	FO31	0295
0320	32	FHP 0305	0M032	1320	2320	FO32	0305
0330	33	FHP 0315	0M033	1330	2330	FO33	0315
0340	34	FHP 0325	0M034	1340	2340	FO34	0325
0345	34.5		.... .	1345		FO34½	
0350	35	FHP 0335	0M035	1350	2350	FO35	0335
0355	35.5	. .	..... .	1355	2355	FO35½	
0360	36	FHP 0345	0M036	1360	2360	FO36	0345
0370	37	FHP 0355	0M037	1370	2370	FO37	0355
0380	38	FHP 0365	0M038	1380	2380	FO38	0365
0390	39	FHP 0375	0M039	1390	2390	FO39	0375
0400	40	FHP 0385	0M040	1400	2400	FO40	0385
0410	41	FHP 0395	0M041	1410	2410	FO41	0395
0420	42	FHP 0405	0M042	1420	2420	FO42	0405
0430	43	FHP 0415	0M043	1430	2430	FO43	0415
0440	44	FHP 0425	0M044	1440	2440	......	0425
0450	45	FHP 0435	0M045	1450	....	FO45	0435
0460	46	FHP 0445	0M046	1460	....	......	0445
0470	47	FHP 0455	0M047	1470	2470	FO47	0455
0480	48	FHP 0465	0M048	....	....	......	0465
0490	49	FHP 0475	0M049	1490	2490	......	0475
0500	50	FHP 0485	0M050	....	....	......	0485
0510	51	FHP 0495	0M051	....	....	......	0495
0520	52	FHP 0505	0M052	....	....	....	0505
0530	53	FHP 0515	0M053	....	2530	......	0515
0550	55	FHP 0535	0M055	....	....	......	0535
0570	57	FHP 0555	0M057	....	....	......	0555
0580	58	FHP 0565	0M058	1580	2580	FO58	0565
0600	60	FHP 0585	0M060	1600	2595	. ..	0585
0610	61	FHP 0595	0M061	1610	....	FO61	0595
0665	66.5						
0675	67.5	... ...	..	1675	....	FO67½	

TABLE 28. LIGHT-DUTY V-BELT CONVERSION CHART.—(*Continued*)
Standard No. 1,000 (*A-section*)
½ in. top width × 5⁄16 in. thickness × 40-deg angle.

Allis-Chalmers Diamond B. F. Goodrich Pyott Thermoid T. B. Woods Belt No	*Outside length, in.*	*Browning*	*Dayton*	*Gates*	*Gilmer*	*Goodyear*	*Manhattan*
1170	17	FHP 115	......	2170	...	....	1150
1180	18						
1190	19	FHP 117	.....	2190	3190	....	1170
1200	20	FHP 118	1M020	2200	3200	FA20	1180
1210	21	FHP 119	1M021	2210	3210	FA21	1190
1215	21.5	....	......	....	3215		
1220	22	FHP 120	1M022	2220	3220	FA22	1200
1230	23	FHP 121	1M023	2230	3230	FA23	1210
1240	24	FHP 122	1M024	2240	3240	FA24	1220
1250	25	FHP 123	1M025	2250	3250	FA25	1230
1260	26	FHP 124	1M026	2260	3260	FA26	1240
1270	27	FHP 125	1M027	2270	3270	FA27	1250
1280	28	FHP 126	1M028	2280	3280	FA28	1260
1290	29	FHP 127	1M029	2290	3290	FA29	1270
1300	30	FHP 128	1M030	2300	3300	FA30	1280
1310	31	FHP 129	1M031	2310	3310	FA31	1290
1315	31.5	..	....	2315	3315		
1320	32	FHP 130	1M032	2320	3320	FA32	1300
1330	33	FHP 131	1M033	2330	3330	FA33	1310
1340	34	FHP 132	1M034	2340	3340	FA34	1320
1350	35	FHP 133	1M035	2350	3350	FA35	1330
1360	36	FHP 134	1M036	2360	3360	FA36	1340
1370	37	FHP 135	1M037	2370	3370	FA37	1350
1380	38	FHP 136	1M038	2380	3380	FA38	1360
1390	39	FHP 137	1M039	2390	3390	FA39	1370
1400	40	FHP 138	1M040	2400	3400	FA40	1380
1405	40.5	.	....	2405			
1410	41	FHP 139	1M041	2410	3410	FA41	1390
1415	41.5	...	.	...	3415		
1420	42	FHP 140	1M042	2420	3420	FA42	1400
1430	43	FHP 141	1M043	2430	....	FA43	1410
1440	44	FHP 142	1M044	2440	3440	FA44	1420
1450	45	FHP 143	1M045	2450	3450	FA45	1430
1460	46	FHP 144	1M046	2460	3460	FA46	1440
1470	47	FHP 145	1M047	2470	3470	FA47	1450
1480	48	FHP 146	1M048	2480	3480	FA48	1460
1490	49	FHP 147	1M049	2490	3490	FA49	1470
1500	50	FHP 148	1M050	2500	3500	FA50	1480
1510	51	FHP 149	1M051	2510	3510	....	1490
1520	52	FHP 150	1M052	2520	3520	FA52	1500
1530	53	FHP 151	1M053	2530	3530	FA53	1510
1540	54	FHP 152	1M054	2540	3540	FA54	1520
1545	54.5	.	......	....	3545		
1550	55	FHP 153	1M055	2550	3550	....	1530
1560	56	FHP 154	1M056	2560	3560	FA56	1540
1570	57	FHP 155	1M057	2570	3570	....	1550
1575	57.5						
1580	58	FHP 156	1M058	2580	3580	FA58	1560
1590	59	FHP 157	1M059	2590	.	. .	1570
1600	60	FHP 158	1M060	2600	3600	FA60	1580

TABLE 28. LIGHT-DUTY V-BELT CONVERSION CHART.—(*Continued*)

Standard No. 1,000 (*A-section*)

½ in. top width × 5/16 in. thickness × 40-deg angle.

Allis-Chalmers Diamond B. F Goodrich Pyott Thermoid T. B. Woods Belt No.	*Outside length, in.*	*Browning*	*Dayton*	*Gates*	*Gilmer*	*Goodyear*	*Manhattan*
1610	61	FHP 159	1M061	2610	3610	....	1590
1620	62	FHP 160	1M062	2620	3620	FA62	1600
1630	63	FHP 161	1M063	2630	3630	....	1610
1640	64	FHP 162	1M064	2640	....	FA64	1620
1650	65	FHP 163	1M065	2650	3650	....	1630
1655	65.5	....	......	2655			
1660	66	FHP 164	1M066	2660	3660	FA66	1640
1670	67	FHP 165	1M067	2670	3670	....	1650
1675	67.5						
1680	68	FHP 166	1M068	2680	....	FA68	1660
1690	69	FHP 167	1M069	2690	....	....	1670
1700	70	FHP 168	1M070	2700	3700	FA70	1680
1710	71	FHP 169	1M071	2710	....	....	1690
1720	72	FHP 170	1M072	2720	....	FA72	1700
1730	73	FHP 171	1M073	2730	....	....	1710
1740	74	FHP 172	1M074	2740	3740	FA74	1720
1750	75	FHP 173	1M075	2750	....	....	1730
1760	76	FHP 174	1M076	2760	3760	FA76	1740
1770	77	FHP 175	1M077	2770	3770	....	1750
1780	78	FHP 176	1M078	2780	....	FA78	1760
1800	80	FHP 177	1M080	2800	3800	FA80	1770
1820	82	FHP 180	1M082	2820	3820	FA82	1800
1830	83						
1840	84	FHP 182	1M084	2840	....	FA84	1820
1850	85	FHP 183	......	2850	3850	....	1830
1860	86	FHP 184	1M086	2860	....	FA86	1840
1870	87	FHP 185	......	2870	3870	....	1850
1880	88	FHP 186	1M088	2880	....	FA88	1860
1890	89						
1900	90	FHP 188	1M090	2900	3900	FA90	1880
1920	92	FHP 190	1M092	2920	3920	FA92	1900
1930	93	FHP 192	......	2940	....	FA94	1920
1940	94	. ...	1M094				
1960	96	FHP 194	1M096	2960	3960	FA96	1940
1980	98	FHP 196	1M098	2980	3980	FA98	1960
11000	100	FHP 198	1M100	21,000	....	....	1980

Standard No. 2,000 (*B-section*)

21/32 in. top width × ⅜ in. thickness × 40-deg angle.

2250	25	FHP 222	2M025	3250	....	FB25	2220
2260	26	FHP 223	2M0.6	3260	....	FB26	2230
2270	27	FHP 224	2M027	3270	....	FB27	2240
2280	28	FHP 225	2M028	3280	....	FB28	2250
2290	29	FHP 226	2M029	3290	4290	FB29	2260
2300	30	FHP 227	2M030	3300	....	FB30	2270
2310	31	FHP 228	2M031	3310	....	FB31	2280
2320	32	FHP 229	2M032	3320	4320	FB32	2290
2325	32 5						
2330	33	FHP 230	2M033	3330	....	FB33	2300

TABLE 28. LIGHT-DUTY V-BELT CONVERSION CHART.—(*Continued*)
Standard No. 2,000 (*B-section*)
$^{21}/_{32}$ in. top width × $^{3}/_{8}$ in. thickness × 40-deg angle.

Allis-Chalmers Diamond B. F. Goodrich Pyott Thermoid T. B. Woods Belt. No.	*Outside length, in.*	*Browning*	*Dayton*	*Gates*	*Gilmer*	*Goodyear*	*Manhattan*
2340	34	FHP 231	2M034	3340	4340	FB34	2310
2350	35	FHP 232	2M035	3350	4350	FB35	2320
2360	36	FHP 233	2M036	3360	4360	FB36	2330
2365	36.5	....	..... .	....	4365		
2370	37	FHP 234	2M037	3370	....	FB37	2340
2380	38	FHP 235	2M038	3380	4380	FB38	2350
2390	39	FHP 236	2M039	3390	4390	FB39	2360
2400	40	FHP 237	2M040	3400	4400	FB40	2370
2410	41	FHP 238	2M041	3410	4410	FB41	2380
2420	42	FHP 239	2M042	3420	....	FB42	2390
2430	43	FHP 240	2M043	3430	....	FB43	2400
2440	44	FHP 241	2M044	3440	4440	FB44	2410
2450	45	FHP 242	2M045	3450	4450	FB45	2420
2460	46	FHP 243	2M046	3460	4460	FB46	2430
2470	47	FHP 244	2M047	3470	4470	FB47	2440
2480	48	FHP 245	2M048	3480	....	FB48	2450
2490	49	FHP 246	2M049	3490	4490	FB49	2460
2500	50	FHP 247	2M050	3500	4500	FB50	2470
2505	50.5						
2510	51	FHP 248	2M051	3510	4510	....	2480
2515	51.5						
2520	52	FHP 249	2M052	3520	4520	FB52	2490
2530	53	FHP 250	2M053	3530	4530	....	2500
2540	54	FHP 251	2M054	3540	4540	FB54	2510
2550	55	FHP 252	2M055	3550	....	....	2520
2560	56	FHP 253	2M056	3560	4560	FB56	2530
2570	57	FHP 254	2M057	3570	4570	....	2540
2575	57.5	... .	......	3575			
2580	58	FHP 255	2M058	3580	4580	FB58	2550
2590	59	FHP 256	2M059	3590	4590	....	2560
2600	60	FHP 257	2M060	3600	4600	FB60	2570
2610	61	FHP 258	2M061	3610	4610	....	2580
2620	62	FHP 259	2M062	3620	4620	FB62	2590
2630	63	FHP 260	2M063	3630	4630	....	2600
2640	64	FHP 261	2M064	3640	4640	FB64	2610
2650	65	FHP 262	2M065	3650	....	....	2620
2655	65.5						
2660	66	FHP 263	2M066	3660	4660	FB66	2630
2670	67	FHP 264	2M067	3670	4670	....	2640
2680	68	FHP 265	2M068	3680	4680	FB68	2650
2690	69	FHP 266	2M069	3690	4690	....	2660
2700	70	FHP 267	2M070	3700	4700	FB70	2670
2710	71	FHP 268	2M071	3710	4710	....	2680
2720	72	FHP 269	2M072	3720	4720	FB72	2690
2730	73	FHP 270	2M073	3730	4730	....	2700
2740	74	FHP 271	2M074	3740	4740	FB74	2710
2750	75	FHP 272	2M075	3750	....	....	2720
2760	76	FHP 273	2M076	3760	4760	FB76	2730
2770	77	FHP 274	2M077	3770	....	....	2740
2780	78	FHP 275	2M078	3780	4780	FB78	2750

TABLE 28. LIGHT-DUTY V-BELT CONVERSION CHART.—(*Continued*)
Standard No. 2,000 (*B-section*)
$^{21}/_{32}$ in. top width × $^{3}/_{8}$ in. thickness × 40-deg angle.

Allis-Chalmers Diamond B. F. Goodrich Pyott Thermoid T. B. Woods Belt No.	*Outside length, in.*	*Browning*	*Dayton*	*Gates*	*Gilmer*	*Goodyear*	*Manhattan*
2800	80	FHP 277	2M080	3800	4800	FB80	2770
2810	81						
2820	82	FHP 279	2M082	3820	4820	FB82	2790
2830	83	....	......	3830			
2840	84	FHP 281	2M084	3840	4840	FB84	2810
2850	85						
2860	86	FHP 283	2M086	3860	4860	....	2830
2870	87						
2880	88	FHP 285	2M088	3880	4880	FB88	2850
2890	89						
2990	90	....	2M090	3900			
2910	91	....	......	....	4910		
2920	92	FHP 289	2M092	3920	....	FB92	2890
2930	93	FHP 290	......	3930	4930	....	2990
2940	94	....	2M094	3940			
2950	95	....	......	3950			
2960	96	FHP 293	2M096	3960	4960	FB96	2930
2970	97						
2980	98	....	2M098	3980	4980	FB98	
2990	99	....	....	....	4990		
21000	100	FHP 297	2M100	31000	....	FB100	2970

face width in the form of iron or steel rings fastened to the sheave rim edges.

Example: Calculate WR^2 for C-section belt sheave having a 50-inch pitch diameter and $7\frac{3}{8}$-inch face width.

Step 1. 30 psi of width
Step 2. $7.375 \times 30 = 221.25 \text{ lb} = W$
Step 3. $^{50}/_{2} = 25$ in. pitch radius
subtracting 0.531 in. (from table)
$25 - 0.531 = 24.469$ in. mean radius
Step 4. $WR^2 = 221.25 \times \left(\frac{24.469}{12}\right)^2 = 920.8 \text{ lb-ft}^2$

V-FLAT DRIVES

A V-flat drive consists of one or more V-belts operating on a small grooved sheave and driving a large ungrooved pulley. Although a crowned pulley may be used, a straight-faced one is preferable. The speed ratio should be 3:1 or higher, and the shaft center distance relatively short. These conditions produce a favorable relationship between the area of belt in contact with sheave and pulley. For example, when the speed ratio

is 3:1 and the center distance equivalent to the diameter of the flat pulley, the arc of contact on the grooved sheave will be about 140 degrees and on the large pulley, 220 degrees. Thus the belt length in contact with the pulley is about 4.7 times that in contact with sheave, making the area of belt contact on the pulley about equal to the area of contact on the sides of the sheave grooves. In a multiple drive, when the flat pulley is crowned, no belt should be permitted to run in its center.

A V-flat drive is economical because no large, grooved sheave has to be purchased. In the selection of standard V-flat drives, manufacturers' tables are usually consulted, in the same manner that standard V-V tables are used. However, when it is necessary to work out designs for V-flat drives not shown in the tables, the following procedure may be used (Some of the steps are the same as for V-V drives):

Steps 1, 2, 3, and 4. Proceed the same as for V-V drives (see page 91).

Step 5. Determine pitch diameters of small sheave and flat pulley:

a. When flat-pulley diameter is known (1) determine flat-pulley pitch diameter by adding appropriate factor for belt section used, as shown in Table 29. (2) Calculate pitch diameter of small sheave by dividing flat-pulley pitch diameter by speed ratio. Use nearest stock diameter when possible.

b. When diameters of sheave and pulley are both unknown. (1) From Table 18 select an arbitrary sheave diameter within the range for the belt section to be used. (2) Calculate pitch diameter of pulley by multiplying the arbitrary sheave pitch diameter by the speed ratio. (3) Find outside diameter of pulley by subtracting from the pitch diameter the appropriate value shown in Table 29. If the answer is a fraction, vary pitch diameter of sheave or the speed ratio until an even pulley diameter is obtained.

Step 6. Determine center distance as follows: Proceed as in Step 7 of the calculations for V-V belts (page 94). In the formula, the letter D will signify pitch diameter of flat pulley in inches (see Table 29).

TABLE 29. DIFFERENCE BETWEEN PULLEY OUTSIDE DIAMETER AND PULLEY PITCH DIAMETER

To obtain	*Belt size*				
	A	*B*	*C*	*D*	*E*
Pitch diameter add to O.D., in.	0 30	0.40	0 60	0.80	0.95

Step 7. Same as Step 8 for V-V belts (page 100). In the calculations, D is pitch diameter of flat pulley (see Table 29).

Step 8. Determine number of belts, which equals

$$\frac{\text{Design horsepower}}{\text{Horsepower per belt}}$$

From Table 30, select the width of the flat pulley necessary to accommodate the number of belts required.

TABLE 30. WIDTH OF FLAT PULLEY FACE FOR V-BELTS, INCHES*

No. of belts	*Belt section*				
	A	*B*	*C*	*D*	*E*
1	$1\frac{1}{2}$	2	3	3	4
2	2	3	4	5	6
3	3	3	5	6	8
4	3	4	6	8	9
5	4	5	7	9	11
6	5	6	8	10	13
7	5	7	9	12	15
8	6	7	10	13	16
9	7	8	11	15	18
10	7	9	12	16	20
11	8	10	13	18	22
12	8	10	14	19	23
13	9	11	15	21	25
14	10	12	16	22	27
Add for each belt over 14.	$\frac{5}{8}$	$\frac{3}{4}$	1	$1\frac{7}{16}$	$1\frac{3}{4}$

* The face widths shown above are minimum and should only be used if the centers are short, alignment good, and the pulley face true and flat. If conditions are not ideal or long centers are used, it is advisable to increase the face width accordingly.

When possible, flat pulleys should be ordered in face widths of even inches to avoid delays and price extras, 10 inches, 12 inches, etc.

V-BELT QUARTER-TURN DRIVES

A quarter-turn V-belt drive is one in which the driver and the driven shafts are at right angles to each other. Transmitting power from gas engines to vertical turbine pumps and from vertical water turbines to horizontal generators are examples of quarter-turn setups.

The designing of quarter-turn V-belt drives is done by the same pro-

cedure as that used for standard V-V drives, but the following differences should be noted:

1. When the drive is like that shown in Fig. 14, the center distance between shafts should be 5.5 to 6 times $(D + W)$, where D is the pitch

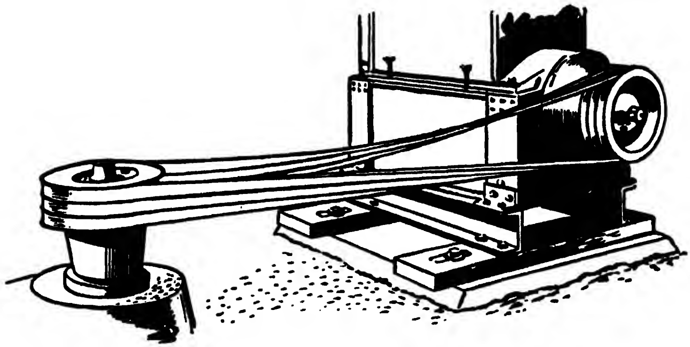


Fig. 13. Typical quarter-turn V-belt drive in which a gas engine operates a vertical turbine pump. This is the simplest form of such a drive. Engine can be moved for belt take-up.

diameter of the large sheave and W is the width of the band of belts, as shown in Table 31.

2. No arc of contact correction is necessary.

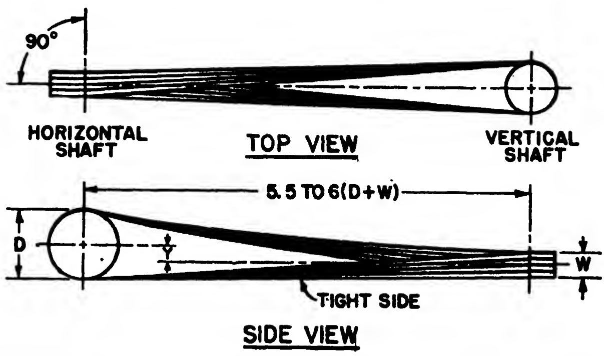


Fig. 14. When a quarter-turn drive is viewed from above, a straight line drawn through the center of the vertical shaft should pass through the horizontal-shaft sheave at its center, and the horizontal shaft should be at right angles to this line. When the same drive is viewed from the side, the horizontal-shaft center should be a distance Y above a level line extending through the center of the vertical-shaft sheave face. Values of Y are shown in Table 32.

3. Deep grooved sheaves should be used on quarter-turn drives.

Setting up Quarter-turn Drive. 1. The tight side of the drive should always be on the bottom. Place a horizontal *driving* sheave so its bottom moves away from driven vertical shaft. Place a horizontal *driven*

sheave so its bottom moves toward the vertical driving shaft. Place belts on vertical sheave to produce rotation in direction required.

2. Aligning drive: Alignment should appear as in Fig. 14. The values of Y in Fig. 14 for various center distances are shown in Table 32.

3. Tension adjustment: First, make certain all belts are snug before starting the drive. Regulate the tension so, when running, the middle belt on the slack side will not fall below its groove in the vertical sheave.

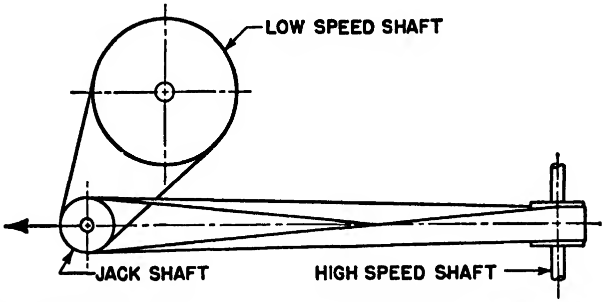


FIG. 15. When speed ratios in a quarter-turn V-belt drive are greater than 2½:1, the arrangement shown above should be used, because the shortest center distance possible with a straight quarter-turn drive would be too great. The drawing shows a conventional quarter-turn drive between the high-speed shaft and a jack shaft, and a straight multiple V-belt drive between the jack shaft and the slow-speed shaft. The jack shaft is movable for belt take-up.

Speed Ratios. The range of speed ratios for quarter-turn drives is from 1:1 to 2½:1. When a greater ratio is desired, a design similar to Fig. 15 may be used. Here the quarter-turn drive is used within its speed limitations to drive a jack shaft, and an auxiliary straight V-V drive is used to transmit power to the driven shaft. The jack shaft may be adjustable to provide take-up.

Designs for quarter-turn V-belt drives should be submitted to belt manufacturers' engineers for checking before the drive is installed.

TABLE 31. WIDTH OF BAND OF BELTS IN INCHES ON DEEP-GROOVED SHEAVES, IN QUARTER-TURN DRIVE

No. of belts	*A*	*B*	*C*	*D*	*E*
1	0.5	0.7	0.9	1.3	1.6
2	1.2	1.6	2.1	2.9	3 6
3	1.8	2.4	3.3	4.6	5.6
4	2.4	3.3	4.5	6.2	7.6
5	3.0	4.2	5.7	7.8	9.6
6	3.7	5.1	6.9	9.4	11.6
7	4.3	5.9	8.1	11.1	13.6
8	4.9	6.8	9.2	12.7	15.6
9	5.5	7.7	10.4	14.3	17.6
10	6.2	8.6	11.6	15.9	19.6
11	6.8	9.4	12.8	17 6	21.6
12	7.4	10.3	14.0	19.2	23.6
13	8.0	11.2	15.2	20.8	25 6
14	8.7	12.1	16.4	22.4	27.6
15	9 3	12.9	17.6	24.1	29.6
16	9.9	13.8	18 8	25.7	31.6
17	10.5	14.7	19.9	27.3	33 6
18	11.2	15.6	21.1	28.9	35 6
19	11 8	16.4	22 3	30.6	37 6
20	12.4	17.3	23 5	32 2	39 6

TABLE 32. ALIGNMENT OF QUARTER-TURN DRIVE (See Fig. 14)

Center Distance, In.	*Dimension Y, In.*
60	$2\frac{1}{2}$
80	$2\frac{1}{4}$
100	3
120	4
140	$5\frac{1}{4}$
160	$6\frac{1}{2}$
180	$7\frac{3}{4}$
200	9
220	$10\frac{1}{2}$
240	12
260	14
280	16
300	18

TABLE 33. MULTI-V BELT COMPARISON

A Cross section A ½ in. wide × 5/16 in. thick				Dayton	Gates	Gilmer
Size No.*	Length, in.			Size No.	Size No.	Size No.
	Inside	Pitch	Outside			
A26	26.0	27.0	28.0	2A8	26A	2A6
A31	31.0	32.0	33.0	3A3	31A	3A1
A35	35.0	36.0	37.0	3A7	35A	3A5
A38	38.0	39.0	40.0	4A0	38A	3A8
A42	42.0	43.0	44.0	4A4	42A	4A2
A46	46.0	47.0	48.0	4A9	46A	4A6
A51	51.0	52 0	53.0	5A4	51A	5A1
A55	55 0	56.0	57.0	5A8	55A	5A5
A60	60.0	61.0	62.0	6A3	60A	6A0
A64	64 0	65.0	66.0	6A7	64A	6A4
A68	68.0	69.0	70.0	7A1	68A	6A8
A75	75 0	76.0	77 0	7A8	75A	7A5
A80	80.0	81.0	82.0	8A3	80A	8A0
A85	85.0	86.0	87 0	8A8	85A	8A5
A90	90.0	91.0	92 0	9A3	90A	9A0
A96	96.0	97.0	98 0	9A9	96A	9A6
A105	105.0	106.0	107.0	1A08	105A	1A05
A112	112.0	113.0	114.0	1A15	112A	1A12
A120	120.0	121 0	122.0	1A23	120A	1A20
A128	128.0	129 0	130.0	1A31	128A	1A28

B Cross section B 21/32 in. wide × 13/32 in. thick				Dayton	Gates	Gilmer
Size No.*	Length, in.			Size No.	Size No.	Size No.
	Inside	Pitch	Outside			
B35	35.0	36.4	37.8	3B7	35B	3B5
B38	38.0	39.4	40.8	4B0	38B	3B8
B42	42.0	43.4	44.8	4B4	42B	4B2
B46	46.0	47.4	48.8	4B9	46B	4B6
B51	51.0	52.4	53.8	5B4	51B	5B1
B55	55.0	56.4	57.8	5B8	55B	5B5
B60	60.0	61.4	62.8	6B3	60B	6B0
B64	64.0	65.4	66.8	6B7	64B	6B4

TABLE 33. MULTI-V BELT COMPARISON.—(*Continued*)

B *Cross section* B				*Dayton*	*Gates*	*Gilmer*
$^{21}/_{32}$ *in. wide* × $^{13}/_{32}$ *in. thick*						
*Size No.**	*Length, in.*			*Size No.*	*Size No.*	*Size No.*
	Inside	*Pitch*	*Outside*			
B68	68.0	69.4	70.8	7B1	68B	6B8
B75	75.0	76 4	77.8	7B8	75B	7B5
B81	81.0	82.4	83.8	8B4	81B	8B1
B85	85.0	86.4	87.8	8B8	85B	8B5
B90	90.0	91.4	92.8	9B3	90B	9B0
B97	97.5	98.4	99 8	9B9	97B	5478
B105	105.0	106.4	107.8	1B08	105B	1B05
B112	112.5	113.4	114.8	1B15	112B	5485
B120	120.0	121.4	122.8	1B23	120B	1B20
B128	128 0	129.4	130.8	1B31	128B	1B28
B136	136.0	137.4	137.8	1B39	136B	1B36
B144	144.0	145.4	146.8	1B47	144B	1B44
B158	158.0	159.4	160 8	1B61	158B	1B58
B173	173.0	174.4	175 8	1B76	173B	1B73
B180	180.0	181.4	182.8	1B84	180B	1B80
B195	195.0	196.4	197.8	1B99	195B	1B95
B210	210.0	211.4	212.8	2B14	210B	2B08
B240	238 6	240.0	241.4	2B44	240B	2B38
B270	268 6	270.0	271.4	2B74	270B	2B68
B300	298 6	300.0	301.4	3B04	300B	2B98

C *Cross section* C				*Dayton*	*Gates*	*Gilmer*
$^{7}/_{8}$ *in. wide* × $^{17}/_{32}$ *in. thick*						
*Size No.**	*Length, in.*			*Size No.*	*Size No.*	*Size No.*
	Inside	*Pitch*	*Outside*			
C51	51.0	52.7	54.4	5C4	51C	5C1
C60	60.0	61.7	63.4	6C3	60C	6C0
C68	68.0	69.7	71.4	7C1	68C	7C1
C75	75.0	76.7	78.4	7C8	75C	7C5
C81	81.0	82.7	84.4	8C4	81C	8C1
C85	84.6	86.7	88.4	8C8	85C	8C5
C90	90.0	91.7	93.4	9C3	90C	9C0
C96	96.0	97.7	99.4	9C9	96C	9C9
C105	105.0	106.7	108.4	1C08	105C	1C05
C112	112.0	113.7	115.4	1C15	112C	1C12

TABLE 33. MULTI-V BELT COMPARISON.—(*Continued*)

C Cross section C, 7/8 in. wide × 17/32 in. thick				Dayton	Gates	Gilmer
*Size No.**	*Length, in.*			*Size No.*	*Size No.*	*Size No.*
	Inside	*Pitch*	*Outside*			
C120	120.0	121.7	123.4	1C23	120C	1C20
C128	128.0	129 7	131.4	1C31	128C	1C28
C136	136.0	137 7	139.4	1C39	136C	1C36
C144	144.0	145 7	147.4	1C47	144C	1C44
C158	158 0	159 7	161.4	1C61	158C	1C58
C162	162.0	163.7	165.4	1C65	162C	1C62
C173	173 0	174.7	176.4	1C76	173C	1C73
C180	180 0	181 7	183.4	1C84	180C	1C80
C195	195.0	196.7	198.4	1C99	195C	1C95
C210	210.0	211.7	213.4	2C14	210C	2C08
C240	238.3	240.0	241.7	2C44	240C	2C38
C270	268.3	270.0	271.7	2C74	270C	2C68
C300	298.3	300.0	301.7	3C04	300C	2C98
C330	328.3	330.0	331.7	3C34	330C	3C28
C360	358.3	360.0	361 7	3C64	360C	3C58
C390	388.3	390.0	391 7	3C94	390C	3C88
C420	418.3	420.0	421 7	4C24	420C	4C18

D Cross section D, 1 1/4 in. wide × 3/4 in. thick				Dayton	Gates	Gilmer
*Size No.**	*Length, in.*			*Size No.*	*Size No.*	*Size No.*
	Inside	*Pitch*	*Outside*			
D120	120.0	122.4	124.8	1D23	120D	1D20
D128	128.0	130.4	132.8	1D31	128D	1D28
D144	144.0	146.4	148.8	1D47	144D	1D44
D158	158.0	160 4	162.8	1D61	158D	1D58
D162	162.0	164.4	166.8	1D65	162D	1D62
D173	173 0	175 4	177 8	1D76	173D	1D73
D180	180.0	182.4	184.8	1D84	180D	1D80
D195	195.0	197.4	199.8	1D99	195D	1D95
D210	210.0	212.4	214.8	2D14	210D	2D08
D240	237.6	240.0	242.4	2D44	140D	2D38
D270	267.6	270.0	272.4	2D74	270D	2D68
D300	297 6	300.0	302.4	3D04	300D	2D98
D330	327.6	330.0	332.4	3D34	330D	3D28

TABLE 33. MULTI-V BELT COMPARISON.—(*Continued*)

D Cross section D — 1¼ in. wide × ¾ in. thick				Dayton	Gates	Gilmer*
Size No.	Length, in.			Size No.	Size No.	Size No.
	Inside	Pitch	Outside			
D360	357.6	360.0	362.4	3D64	360D	3D58
D390	387.6	390.0	392.4	3D94	390D	3D88
D420	417.6	420.0	422.4	4D24	420D	4D18
D480	477.6	480.0	482.4	4D84	480D	4D78
D540	537.6	540.0	542.4	5D44	540D	5D38
D600	597.6	600.0	602.4	6D04	600D	5D98
D660	657.6	660.0	662.4	6D64	660D	

E Cross section E — 1½ in. wide × 29/32 in. thick				Dayton	Gates	Gilmer
Size No.	Length, in.			Size No.	Size No.	Size No.
	Inside	Pitch	Outside			
E180	180.0	182.7	185.4	1E84	180E	1E80
E195	195.0	197.7	200.4	1E99	195E	1E95
E210	210.0	212.7	215.4	2E14	210E	2E08
E240	237.3	240.0	242.7	2E44	240E	2E38
E270	267.3	270.0	272.7	2E74	270E	2E68
E300	297.3	300.0	302.7	3E04	300E	2E98
E330	327.3	330.0	332.7	3E34	330E	3E28
E360	357.3	360.0	362.7	3E64	360E	3E58
E390	387.3	390.0	392.7	3E94	390E	3E88
E420	417.3	420.0	422.7	. .	420E	4E18
E480	477.3	480.0	482.7		480E	4E78
E540	537.3	540.0	542.7		540E	5E38
E600	597.3	600.0	602.7	.	600E	5E98
E660	657.3	660.0	662.7	.	660E	6E58

* Allis-Chalmers, Browning, Diamond, Dodge, B. F. Goodrich, Goodyear, Manhattan.

Chapter 6

FLAT RUBBER BELTING—TRANSMISSION

The family of flat rubber belting includes power-transmission, conveyor, and elevator belting. Essentially, such belting consists of a skeleton of textile cord or fabric or both, having flesh made of suitable rubber compounds. The textile fibers support much of the load and do most of the work, while the rubber acts chiefly as a protective cushioning material that shields the skeleton against moisture, shock, and other sources of damage and that reduces or eliminates friction between the textile elements while maintaining good frictional contact with pulleys.

Because of such properties as uniformity of structures, elasticity, low permanent stretch, constant pliability, resistance to weathering and decay, resistance to chemicals, and good frictional properties without the use of dressings, rubber belting has proved superior to leather, canvas, and other belting materials for practically all types of service.

Power-transmission Belting

While details vary, flat rubber belting used for power transmission may be classified as being of either fabric or cord construction. In a typical fabric-skeleton belt, cotton duck plies impregnated with uncured rubber are placed together, sometimes with skim coats of rubber between, and the whole vulcanized into a strong, unified structure. At the edges of the belt, the fabric may be folded back upon itself, producing a belt with rounded edge, which is usually identified as "folded edge," or it may form a square, foldless edge, a sealer being applied to protect the exposed duck edges. The latter construction is most commonly called "raw edge."

In the cord type of construction, the stress-bearing member is usually composed of textile cords running lengthwise, each surrounded by rubber; and if more than a single layer is used, each is separated from the next by rubber. This construction is weftless, there being no cross threads. Top and bottom plies of the textile reinforcement are of woven duck. While it is customary to cut the edges square, for special applications such as the driving of planers and sugar centrifugals, the duck is folded back to form an envelope.

Judging Belting

While the belting manufacturer conducts extensive tests in order to maintain the quality of his product and to develop improvements, it is not generally possible to judge flat rubber belting on the basis of such "laboratory factors" as tensile strength, friction pull, strength of friction material, and weight of duck. The making of belting is a complex art, and from the consumer's standpoint the best practice is to rely upon the manufacturer's reputation and to judge his belting by its performance.

Some transmission belting "fallacies" that may cause confusion involve the following:

Stitching. It is not necessary to stitch a modern rubber belt to hold it together. Stitching reduces flexibility and is likely to fail early in normal service.

Stretch. It is not true that all stretch should be eliminated from the ideal belt. In elastic stretch, the elongation does not go beyond the elastic limit of the belting. In permanent stretch, the elastic limit is passed and the belting does not return to its former length. Some degree of elastic stretch is desirable in order to absorb shocks, but permanent stretch should be as low as possible. Precise control of stress-strain characteristics depends on many factors such as uniformity of raw materials and their processing, building, and curing or vulcanization.

Tensile Strength. Belief that tensile strength is a reliable measure of power-transmitting capacity is not true. If capacity were in proportion to strength, an endless rubber belt would transmit twice as much power as one having a laced splice, for the lacing is usually less than half as strong as the adjacent belting material. However, in practice, the power-transmitting capacity of a built-endless belt is only about 15 per cent greater than of one made endless by metal lacings.

Cotton Duck. Merely describing the cotton duck used in a belt as being "32 ounce" is no reliable measure of its performance with respect to power transmission and stretch. Several different samples of cotton duck that are identical with respect to the number of warp and filler strands per inch, the yarn size, plies per strand, and ply twists per inch will, after being incorporated into a belt, exhibit different power-transmitting and stretching properties.

The Specification Fallacy. It is a fallacy to declare that a purchaser should specify all the details of construction of belting he wishes to obtain. Selection should be based on service records of known brands. It is difficult to write detailed belting specifications; and if they are included in an order, the buyer may be shutting himself off from possible improvements that have not become known to him.

Pulleys for Flat Transmission Belts

Pulley Width. For pulleys up to 6 inches wide, the belt is usually about 1 inch narrower, *e.g.*, a 5-inch belt on a 6-inch pulley. For pulleys more than 6 inches wide, the difference may range up to or beyond 2 inches.

When pulley and shafting alignment is perfect, less margin between belt and pulley widths is required. Power-transmitting capacity is in proportion to belt width, regardless of pulley width or margin.

Pulley Crown. Pulleys are crowned to make the belt run in the middle. The maximum recommended crown is ⅛ inch per foot of width; *i.e.*, for every foot of pulley width, the difference between center and edge diameter is ⅛ inch. Narrow pulleys may have a crown of 3/16 inch per foot width. The smaller diameter pulley in a pair should have less crown than the larger.

Table 1. Pulley Crown Table

Pulley Width, In.	*Crown (Increase in Pulley Diam. at Middle, In.)*
1	0.0104
2	0.021
3	0.031
4	0.042
5	0.052
6	0.062
7	0.073
8	0.083
9	0.094
10	0.104
11	0 114
12	0.125

For pulleys greater than 1 foot width, multiply each even foot of width by the value for 12 inches (Table 1) and add the value for any additional increment in inches, as given by the table. Thus for a 15 inch wide pulley, which equals 1 foot plus 3 inches, the crown would be 1×0.125 plus 0.031 or 0.156 inch.

Pitch Measurements. The pitch diameter of a flat belt pulley is usually considered the same as the outside diameter, and the pitch length of the belt the same as the length around the inner belt circumference. If the most accurate speed ratio is desired, it is better to consider the pulley pitch diameter to be the pulley outside diameter plus 1.33 times the belt thickness.

Minimum Pulley Diameter. For maximum belt life and performance, the belt thickness (number of plies) and pulley diameter should be matched, as shown in Table 2 for standard B. F. Goodrich belts.

TABLE 2. MINIMUM PULLEY DIAMETERS, INCHES

Thickness	*1,000 fpm*	*3,000 fpm*	*6,000 fpm*
Highflex			
3-ply	3	4	5
4-ply	5	6	8
5-ply	7	8	12
6-ply	10	12	16
7-ply	13	16	20
8-ply	16	20	24
9-ply	19	24	28
10-ply	22	28	32
Highflex, Jr.			
Light single	2	3	4
Medium single	3	4	5
Heavy single	4	5	7
Light double	6	7	10
Medium double	9	11	15
Heavy double	11	13	17
Multicord			
Widths up to 8 in.:			
Extra light	3	3	4
Light	4	5	7
Medium	6	7	10
Heavy	8	10	13
Widths 8 in. and over:			
Extra light	5	7	10
Light	8	10	13
Medium	10	13	16
Heavy	13	16	19
Extra heavy	16	19	23

PULLEY OR SHAFT SPEEDS. The following formulas may be used to calculate speeds of pulleys in relation to pulley diameters. Briefly, the usual procedure is to multiply the diameter of one pulley by its speed in revolutions per minute, then divide the product by the rpm of the second pulley to find the second pulley's diameter or by the second pulley diameter to find its speed.

$$(a)\ D_1 = \frac{D_2R_2}{R_1} \qquad (b)\ D_2 = \frac{D_1R_1}{R_2}$$

$$(c)\ R_1 = \frac{D_2R_2}{D_1} \qquad (d)\ R_2 = \frac{D_1R_1}{D_2}$$

TABLE 3. BELT SPEEDS, FEET PER MINUTE

Diam., in.	Revolutions per minute 75	100	125	150	175	200	225	250	275	300	325	350	375	400	450	500	550	600	650
4	78	105	131	157	183	209	236	262	288	314	340	367	393	419	471	524	576	628	681
5	98	131	164	196	229	262	295	327	360	393	425	458	491	524	589	654	720	785	851
6	118	157	196	236	275	314	353	393	432	471	511	550	589	628	707	785	864	942	1,021
7	138	183	229	275	320	367	412	458	504	550	596	641	687	733	825	916	1,008	1,100	1,191
8	157	209	262	314	367	419	471	524	576	628	681	733	785	838	942	1,047	1,152	1,257	1,361
9	177	236	295	353	412	471	530	589	648	707	766	825	884	942	1,060	1,178	1,296	1,414	1,531
10	196	262	327	393	458	524	589	654	720	785	851	916	982	1,047	1,178	1,309	1,440	1,571	1,702
12	236	314	393	471	550	628	707	785	864	942	1,021	1,100	1,178	1,257	1,414	1,571	1,728	1,885	2,042
14	275	367	458	550	641	733	825	916	1,008	1,100	1,191	1,283	1,375	1,466	1,649	1,833	2,016	2,199	2,382
15	295	393	491	589	687	785	884	982	1,080	1,178	1,276	1,375	1,473	1,571	1,767	1,964	2,160	2,356	2,553
16	314	419	524	628	733	838	942	1,047	1,152	1,257	1,361	1,466	1,571	1,675	1,885	2,094	2,304	2,513	2,723
18	353	471	589	707	825	942	1,060	1,178	1,296	1,414	1,531	1,649	1,767	1,885	2,121	2,356	2,592	2,827	3,063
20	393	524	654	785	916	1,047	1,178	1,309	1,440	1,571	1,702	1,833	1,964	2,094	2,356	2,618	2,880	3,142	3,403
22	432	576	720	864	1,008	1,152	1,296	1,440	1,584	1,728	1,872	2,016	2,160	2,304	2,592	2,880	3,168	3,456	3,744
24	471	628	785	942	1,100	1,257	1,414	1,571	1,728	1,885	2,042	2,199	2,356	2,513	2,827	3,142	3,456	3,770	4,084
26	511	681	851	1,021	1,191	1,361	1,531	1,702	1,872	2,042	2,212	2,382	2,553	2,723	3,063	3,403	3,744	4,084	4,424
28	550	733	916	1,100	1,283	1,466	1,649	1,833	2,016	2,199	2,382	2,566	2,749	2,932	3,299	3,665	4,032	4,398	4,764
30	589	785	982	1,178	1,375	1,571	1,767	1,964	2,160	2,356	2,553	2,749	2,945	3,142	3,534	3,927	4,320	4,712	5,105
32	628	838	1,047	1,257	1,466	1,675	1,885	2,094	2,304	2,513	2,723	2,932	3,142	3,351	3,770	4,189	4,608	5,027	5,445
34	668	890	1,113	1,335	1,558	1,780	2,003	2,225	2,448	2,670	2,893	3,115	3,338	3,560	4,006	4,451	4,896	5,341	5,785
36	707	942	1,178	1,414	1,649	1,885	2,121	2,356	2,592	2,827	3,063	3,299	3,534	3,770	4,241	4,712	5,184	5,655	6,126
38	746	995	1,244	1,192	1,741	1,990	2,238	2,487	2,736	2,985	3,233	3,482	3,731	3,979	4,477	4,974	5,472	5,969	6,466
40	785	1,047	1,309	1,571	1,833	2,094	2,356	2,618	2,880	3,142	3,403	3,665	3,927	4,189	4,712	5,236	5,760	6,283	
42	825	1,100	1,375	1,649	1,924	2,199	2,474	2,749	3,024	3,299	3,574	3,848	4,123	4,398	4,948	5,498	6,048	6,597	
44	864	1,152	1,440	1,728	2,016	2,304	2,592	2,880	3,168	3,456	3,744	4,032	4,320	4,608	5,184	5,760	6,336		
46	903	1,204	1,505	1,806	2,108	2,408	2,710	3,011	3,312	3,613	3,914	4,215	4,516	4,817	5,419	6,021	6,623		
48	942	1,257	1,571	1,885	2,199	2,513	2,827	3,142	3,456	3,770	4,084	4,398	4,712	5,027	5,655	6,283			
54	1,060	1,414	1,767	2,121	2,474	2,827	3,181	3,534	3,888	4,241	4,595	4,948	5,302	5,655	6,362				
60	1,178	1,571	1,964	2,356	2,749	3,142	3,534	3,927	4,320	4,712	5,105	5,498	5,890	6,283					
66	1,296	1,728	2,160	2,592	3,024	3,456	3,888	4,320	4,752	5,184	5,616	6,048							
72	1,414	1,885	2,356	2,827	3,299	3,770	4,241	4,712	5,184	5,655	6,126	6,597							
84	1,649	2,199	2,749	3,299	3,848	4,398	4,948	5,498	6,048	6,597	7,148								
96	1,885	2,513	3,142	3,770	4,398	5,027	5,655	6,283	6,912										
108	2,121	2,827	3,534	4,241	4,948	5,655	6,362												
120	2,356	3,142	3,927	4,712	5,498	6,283	7,069												
132	2,592	3,456	4,320	5,184	6,048	6,912	7,776												
144	2,827	3,770	4,712	5,655	6,597														
156	3,063	4,084	5,105	6,126	7,148														
168	3,299	4,398	5,498	6,597															
180	3,534	4,712	5,890																

Diam., in.	Revolutions per minute																			
	700	750	800	850	900	950	1,000	1,100	1,200	1,300	1,400	1,500	1,600	1,700	1,800	1,900	2,000	2,200	2,400	2,600
4	733	785	838	890	942	995	1,047	1,152	1,257	1,361	1,466	1,571	1,675	1,780	1,885	1,990	2,095	2,304	2,513	2,723
5	916	982	1,047	1,113	1,178	1,244	1,309	1,440	1,571	1,702	1,833	1,964	2,094	2,225	2,356	2,487	2,618	2,880	3,142	3,403
6	1,100	1,178	1,257	1,335	1,414	1,492	1,571	1,728	1,885	2,042	2,199	2,356	2,513	2,670	2,827	2,984	3,142	3,456	3,770	4,084
7	1,283	1,375	1,466	1,558	1,649	1,741	1,833	2,016	2,199	2,382	2,566	2,749	2,932	3,115	3,299	3,482	3,665	4,032	4,398	4,764
8	1,466	1,571	1,675	1,780	1,885	1,990	2,094	2,304	2,513	2,723	2,932	3,142	3,351	3,560	3,770	3,979	4,189	4,608	5,027	5,445
9	1,649	1,767	1,885	2,003	2,121	2,238	2,356	2,592	2,827	3,063	3,299	3,534	3,770	4,006	4,241	4,477	4,712	5,184	5,655	6,126
10	1,833	1,964	2,094	2,225	2,356	2,487	2,618	2,880	3,142	3,403	3,665	3,927	4,189	4,451	4,712	4,974	5,236	5,760	6,283	
12	2,199	2,356	2,513	2,670	2,827	2,984	3,142	3,456	3,770	4,084	4,398	4,712	5,027	5,341	5,655	5,969	6,283			
14	2,566	2,749	2,932	3,115	3,299	3,482	3,665	4,032	4,398	4,764	5,131	5,498	5,864	6,231	6,597					
15	2,749	2,945	3,142	3,338	3,534	3,731	3,927	4,320	4,712	5,105	5,498	5,890	6,283	6,676						
16	2,932	3,142	3,351	3,560	3,770	3,979	4,189	4,608	5,027	5,445	5,864	6,283	6,702							
18	3,299	3,534	3,770	4,006	4,241	4,477	4,712	5,184	5,655	6,126	6,597									
20	3,665	3,927	4,189	4,451	4,712	4,974	5,236	5,760	6,283											
22	4,032	4,320	4,608	4,896	5,184	5,472	5,760	6,336												
24	4,398	4,712	5,027	5,341	5,655	5,969	6,283													
26	4,764	5,105	5,445																	
28	5,131	5,498	5,864																	
30	5,498	5,890	6,283																	
32	5,864	6,283	6,702																	
34	6,231	6,676																		

Diam., in	Revolutions per minute							
	2,800	3,000	3,200	3,400	3,600	3,800	4,000	4,400
4	2,932	3,142	3,351	3,560	3,770	3,979	4,189	4,608
5	3,665	3,927	4,189	4,451	4,712	4,974	5,236	5,760
6	4,398	4,712	5,027	5,341	5,655	5,969	6,283	
7	5,131	5,498	5,864	6,231	6,597			
8	5,864	6,283	6,702					
9	6,597							

where D_1 = diameter of driving pulley
D_2 = diameter of driven pulley
R_1 = rpm of driving pulley
R_2 = rpm of driven pulley

PREFERABLE SPEEDS. Large pulley diameters and consequently higher belt speeds are preferable wherever they can be used. The most economical belt speed is around 4,000 to 4,500 feet per minute. Large pulleys provide better belt contact and thus reduce slipping. Small pulleys, besides increasing the tendency of the belt to slip, increase belt flexing and thus tend to shorten its life as a result of ply separation and excessive stretching of the outside plies. A high belt speed permits the use of a smaller belt cross section for transmitting a given horsepower.

BELT SPEED. Multiply the circumference of either pulley, in feet, by the revolutions per minute of the same pulley, to obtain feet per minute belt travels.

Thus,

$$S = 3.1416D \times \text{rpm}$$

where D = pulley diameter in feet

S = speed of belt in feet per minute

Or

$$S = 0.262d \times \text{rpm}$$

where d = diameter of pulley in inches

When exact speed figures are desired, correction for belt thickness should be made by adding 1.33 times belt thickness to pulley diameter.

Belt speeds for commonly used pulleys are given in Table 3.

HORSEPOWER CAPACITY OF FLAT TRANSMISSION BELTING

Calculation of the horsepower a rubber belt will transmit at a certain speed with negligible slip is based upon the assumption that heavy rubber-fabric belting exerts an effective pull of 13¾ pounds for each ply of fabric 1 inch wide. At a belt speed of 2,400 feet per minute, 1 horsepower is transmitted by each 1 inch of ply (13¾ × 2,400 = 33,000 foot-pounds = 1 horsepower). At 600 feet per minute, only ¼ horsepower would be transmitted; at 1,200 feet per minute, ½ horsepower, etc.

Formulas used in calculating horsepower are

$$H = \frac{SWP}{2{,}400} \qquad P = \frac{2{,}400H}{SW}$$

$$W = \frac{2{,}400H}{SP} \qquad S = \frac{2{,}400H}{WP}$$

where H = horsepower
S = belt speed in feet per minute
W = belt width in inches
P = number of plies

Sometimes the belting construction is such that the number of plies either is not apparent or cannot be applied as just indicated. Thus, some cord-type belting has no conventional ply construction, and factors indicating the equivalent plies must be used. Table 4 shows the values of P for B. F. Goodrich Multicord and Highflex Jr. belting.

TABLE 4. VALUE OF P FOR CORD BELTING

Multicord belting			
Thickness	*Widths under 8 in.*	*8- to 10-in. widths*	*10- to 28-in. widths*
Extra light.	3	4	5
Light	4	5	6
Medium.	5	6	7
Heavy.	6	7	8

Highflex, Jr. belting	
Thickness	*Value of P*
Light single.	2.65
Medium single. . .	2.9
Heavy single. . .	3.2
Light double . .	3.6
Medium double	4.1
Heavy double . . .	4.4

CORRECTIONS OF HORSEPOWER CAPACITY. Because of various conditions affecting power transmission, the horsepower calculated by the formulas may not be the actual horsepower of the drive. And so the horsepower either found by use of the formulas or taken from tables of horsepower capacity has to be multiplied by one or more correction factors.

Pulley-diameter Horsepower Correction. Find the nearest pulley diameter in Table 6, and multiply the horsepower rating of belt by the factor opposite it, under the type of belting used.

Arc-of-contact Correction. For a greater or lesser wrap of belt around pulley than the normal 180 degrees, the horsepower figures must be

TABLE 5. HORSEPOWER CAPACITY
Heavy fabric and cord rubber belts for pulleys 12 in. and larger*

Size of belt, in.		Belt speed, fpm									
Highflex	Multicord	500	1,000	1,500	2,000	2,500	3,000	3,500	4,000	5,000	6,000
1 3 ply	1 Ex. lt.	0.6	1.3	1.9	2.5	3.1	3.8	4.4	5	6.3	7.5
1½ 3 ply	1½ Ex. lt.	0.9	1.9	2.8	3.8	4.7	5.1	6.6	7.5	9.4	11.0
2 3 ply	2 Ex. lt.	1.3	2.5	3.8	5	6.3	7.5	8.8	10	13	15
2 4 ply	2 Light	1.7	3.3	5.0	6.7	8.3	10	12	13	17	20
2½ 3 ply	2½ Ex. lt.	1.6	3.1	4.7	6.3	7.8	9.4	11	13	16	19
2½ 4 ply	2½ Light	2.1	4.2	6.2	5.3	10.4	12.5	14.5	17	21	25
3 3 ply	3 Ex. lt.	1.9	3.8	5.6	7.5	9.4	11	13	15	19	23
3 4 ply	3 Light	2.5	5.0	7.5	10	13	15	18	20	25	30
3 5 ply	3 Medium	3.1	6.3	9.4	13	16	19	22	25	31	38
3½ 4 ply	3½ Light	2.9	5.8	8.8	12	15	18	20	23	29	32
4 3 ply	4 Ex. lt.	2.5	5.0	7.5	10	13	15	18	20	25	30
4 4 ply	4 Light	3.3	6.7	10	13	17	20	23	27	33	40
4 5 ply	4 Medium	4.2	8.3	13	17	21	25	29	33	42	50
4 6 ply	4 Heavy	5.0	10	15	20	25	30	35	40	50	60
5 3 ply	5 Ex. lt.	3.1	6.3	9.4	13	16	19	22	25	31	38
5 4 ply	5 Light	4.2	8.3	13	17	21	25	29	33	42	50
5 5 ply	5 Medium	5.2	10	16	21	26	31	36	42	52	63
5 6 ply	5 Heavy	6.3	13	19	25	31	38	44	50	63	75
6 3 ply	6 Ex. lt.	3.8	7.5	11	15	19	23	26	30	38	45
6 4 ply	6 Light	5.0	10	15	20	25	30	35	40	50	60
6 5 ply	6 Medium	6.3	13	19	25	31	38	44	50	63	75
6 6 ply	6 Heavy	7.5	15	23	30	38	45	53	60	75	90
7 3 ply	7 Ex. lt.	4.4	8.8	13	18	22	26	31	35	44	53
7 4 ply	7 Light	5.8	12	18	23	29	35	41	47	58	70
7 5 ply	7 Medium	7.3	15	22	29	36	44	51	58	73	88
7 6 ply	7 Heavy	8.8	18	26	35	44	53	61	70	88	105
8 4 ply	8 Ex. lt.	6.7	13	20	27	33	40	47	53	67	80
8 5 ply	8 Light	8.3	17	25	33	42	50	58	67	83	100
8 6 ply	8 Medium	10	20	30	40	50	60	70	80	100	120
8 7 ply	8 Heavy	12	23	35	47	58	70	82	93	117	140
10 5 ply	10 Ex. lt.	10	21	31	42	52	63	73	83	104	125
10 6 ply	10 Light	13	25	38	50	63	75	88	100	125	150
10 7 ply	10 Medium	15	29	44	58	73	88	102	117	146	175
10 8 ply	10 Heavy	17	33	50	67	83	100	117	133	150	200
12 5 ply	12 Ex. lt.	13	25	38	50	63	75	88	100	125	150
12 6 ply	12 Light	15	30	45	60	75	90	105	120	150	180
12 7 ply	12 Medium	18	35	53	70	88	105	123	140	175	210
12 8 ply	12 Heavy	20	40	60	80	100	120	140	160	200	240
14 6 ply	14 Light	18	35	53	70	88	105	123	140	175	210
14 7 ply	14 Medium	20	41	61	82	102	123	143	163	204	245
14 8 ply	14 Heavy	23	47	70	93	117	140	163	187	233	280
16 6 ply	16 Light	20	40	60	80	100	120	140	160	200	240
16 7 ply	16 Medium	23	47	70	93	117	140	163	187	233	280
16 8 ply	16 Heavy	27	53	80	107	133	160	187	213	240	320
18 6 ply	18 Light	23	45	68	90	113	135	158	180	225	270
18 7 ply	18 Medium	26	53	79	105	131	158	184	210	263	315
18 8 ply	18 Heavy	30	60	90	120	150	180	210	240	300	360
20 6 ply	20 Light	25	50	75	100	125	150	175	200	250	300
20 7 ply	20 Medium	29	58	88	117	146	175	204	233	292	350
20 8 ply	20 Heavy	33	67	100	133	167	200	233	267	333	400
24 6 ply	24 Light	30	60	90	120	150	180	210	240	300	360
24 7 ply	24 Medium	35	70	105	140	175	210	245	280	350	420

* If either driving or driven pulley is smaller than 12″ multiply horsepower by the proper factor from Table 6 or Pulley Diameter Factors.

TABLE 6. PULLEY-DIAMETER CORRECTION FACTORS

Pulley diameter, in.	*Heavy fabric belts*	*Cord belts such as Goodrich Multicord*	*Lightweight belts such as Goodrich Highflex Jr.*
2	....	....	0.6
3	0.5	0.6	0.7
4	0.6	0.7	0.8
5	0.7	0.8	0.9
6	0.7	0.8	1.0
8	0.8	0.9	1.0
10	0 9	1.0	1.0
12 and over	1.0	1.0	1.0

increased or decreased. There are several ways of finding the arc of contact:

1. Calculate the arc of the belt on the smaller pulley with the formula

$$\text{Arc of contact} = 180 \text{ deg.} - \frac{4.8(D - d)}{C}$$

where D and d = diameters of large and small pulleys, respectively, in inches

C = the distance between pulley centers in feet

2. Use the following drawings in selecting the arc involved in your problem (Fig. 1).

3. Use a ruler or draughtsman's triangle on the accompanying scales to determine the arc for the smaller pulley as directed (Fig. 2).

After the arc of contact has been determined, find in Table 7 the correction factor for the arc nearest it. Multiply the horsepower rating by this factor.

TABLE 7. ARC-OF-CONTACT FACTORS

Arc, deg	*Factor*	*Arc, deg*	*Factor*
140	0.80	190	1.04
150	0.85	200	1.08
160	0.90	210	1.11
170	0.95	220	1.13
180	1.00	230	1.16

Pulley-surface Horsepower Correction. Normally the coefficient of friction between a steel pulley and a friction-surface belt (one having a friction coating of rubber) lies between 0.22 and 0.30, increasing with

belt speed. The tables and formulas presented in this chapter are based on the use of cast-iron or steel pulleys. When pulleys have facings of fiber, wood, or paper, the power capacity of the belt is increased 5 to 10 per cent.

Centrifugal-force Correction. The accompanying formulas and tables are based on belt speeds up to 4,000 feet per minute, and no correction for centrifugal force is necessary, partly because any loss of power resulting from it is balanced by the increase of the coefficient of friction with

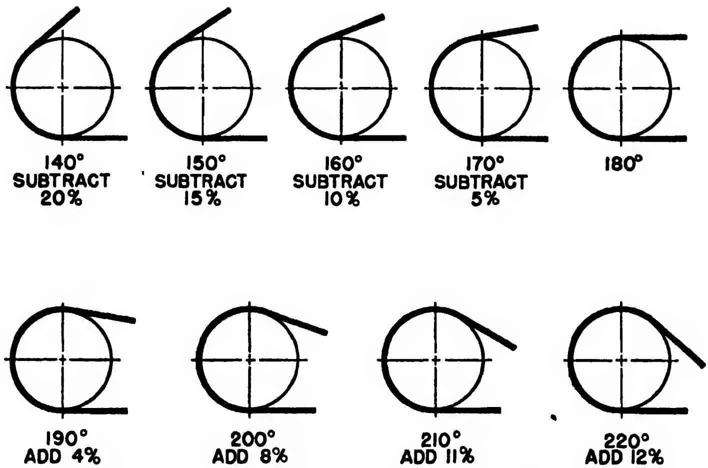


Fig. 1. Effect of different arcs of contact of a flat transmission belt around a pulley. Percentages to be added or subtracted are based on a "normal" arc of 180 degrees. As an example, an arc of contact of 210 degrees would transmit 111 per cent as much horsepower as an arc of 180 degrees, all other conditions being equal.

increase of speed. For the most improved types of rubber belts, no correction is needed up to 6,000 feet per minute, because the resistance to stretch shown by these belts permits initial tension to be increased up to 20 per cent to offset centrifugal tension. Because the additional tension in the belt is balanced by the centrifugal tension, there is no increase of tension on bearings or shafting. For belting that is not of the highest grade, reduce horsepower ratings as follows:

For 5,000 fpm	10%
For 6,000 fpm	15%

Overload Correction. In designing a flat belt drive, adequate allowance should be made for overload. The probable amount of overload varies with machine and drive. The accompanying service-factor table may be used as a guide in estimating overload. When the belt is used where it is subjected to sudden shocks, the foregoing horsepower calculations may

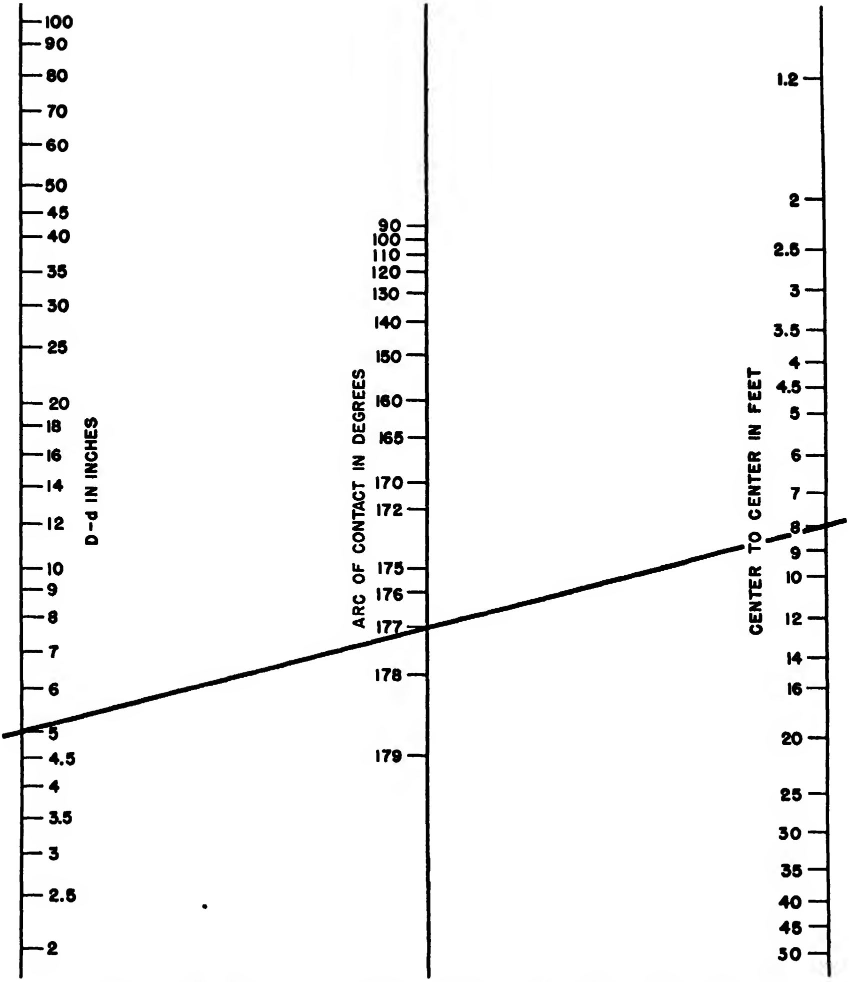


FIG. 2. Arc of contact chart. To determine arc of contact of belt around smaller pulley of a transmission-belt drive, place a ruler to intersect a point on the left-hand scale representing difference, in inches, of diameters of driver and driven pulleys; and to intersect a point on the right-hand scale representing center distance between pulleys, in feet. Arc of contact on smaller pulley is indicated by point where ruler crosses the center scale. The diagonal line on the chart indicates that the arc of contact is 177 degrees around a pulley that is 5 inches smaller in diameter and 8 feet distant from its companion.

not be reliable, and the belt may have to be selected on the basis of past experience.

The service-factor table is used in estimating the horsepower requirements that a belt must be selected to fill. In the table, find the factor corresponding to the driving unit (motor or engine) and type of machine

TABLE 8. SERVICE FACTORS

To estimate horsepower requirement to be used in selecting a belt, multiply the rated horsepower of the driving unit (name-plate rating) by the service factor.

Applications	*Prime movers*														
	Electric motors										*Engines*				
	AC								*DC*		*Gas and diesel*				
	Squirrel cage				*Synchronous*		*Single-phase*								
	Normal torque, line start	*Normal torque, compensator start*	*High torque*	*Wound rotor (slip-ring)*	*Normal torque*	*High torque*	*Repulsion and split-phase*	*Capacitor*	*Shunt-wound*	*Compound-wound*	*4 or more cyl. above 700 rpm*	*4 or more cyl. below 700 rpm*	*3 or less cyl. (refer to fact'y)*	*Steam*	*Line shafts and clutch starting*
Agitators—paddle, propeller:															
Liquid	1.0	1.0	1.2												
Semiliquid	1.2	1.0	1.4	1.2											
Brick and clay machinery:															
Auger machines	...	1.2	1.4	1.4	...	...	...	...	1.4	...	...	...	...	...	2.0
Deairing machines	...	1.2	1.4	1.4	...	...	...	...	1.4	...	...	...	...	...	2.0
Cutting table	...	1.2	1.4	1.4	...	...	...	...	...	...	...	...	...	...	2.0
Pug mill	1.5	1.3	1.8	1.5											
Mixer	...	1.2	1.6	1.4											
Granulator	...	1.2	1.4	1.4											
Dry press	...	1.2	1.6	1.4											
Rolls	...	1.2	1.4	1.4											
Bakery machinery:															
Dough mixer	1.2	...	...	...	...	...	1.2	1.0							
Compressors:															
Centrifugal	1.2	1.2	...	1.4	1.4	...	...	...	1.2	...	1.2				
Rotary	1.2	1.2	...	1.4	1.4	...	1.2	1.2	1.2	...	1.2				
Reciprocating															
3 or more cylinders	1.2	1.2	...	1.4	1.4	...	...	...	1.2						
Conveyors:															
Apron	...	1.4	1.6	...	...	...	...	...	1.4	...	...	...	...	...	1.6
Belt (ore, coal, sand)	...	1.2	1.4	...	...	...	...	...	1.2	...	...	...	...	...	1.4
Belt (light package)	...	1.0	1.1	...	...	...	...	...	1.0	...	...	...	...	...	1.2
Oven	...	1.0	1.1	...	...	...	...	...	1.0	...	...	...	...	...	1.2
Screw	...	1.6	1.8	...	...	...	...	...	1.6	...	...	...	...	...	1.8
Bucket	...	1.4	1.6	...	...	...	...	...	1.4	...	...	...	...	...	1.6
Pan	...	1.4	1.6	...	...	...	...	...	1.4	...	...	...	...	...	1.6
Flight	...	1.6	1.8	...	...	...	...	...	1.6	...	...	...	...	...	1.8
Elevator	...	1.4	1.6	...	...	...	...	...	1.4	...	...	...	...	...	1.6
Crushing machinery:															
Jaw crushers	...	1.4	1.6	1.4	...	...	...	...	...	1.4	1.4	...	...	...	1.6
Gyratory crushers	...	1.4	1.6	1.4	1.4	1.6	...	...	...	1.4	1.4	...	...	...	1.6
Cone crushers	...	1.4	1.6	1.4	...	...	...	...	...	1.6	1.4	...	...	...	1.6
Crushing rolls	...	1.4	1.6	1.4	...	...	...	...	...	1.4	1.4	...	...	...	1.6
Ball—pebble and	...	1.4	1.6	1.4	1.4	1.6	...	...	...	1.4	1.6	...	...	...	1.6
tube mills	...	1.4	1.6	1.4	1.4	...	...	...	...	1.4	...	...	...	...	1.6
Fans and blowers:															
Centrifugal	1.2	1.2	...	1.4	...	...	...	...	1.2	...	1.2				
Propeller	1.4	1.4	2.0	1.6	...	2.0	...	...	1.4	...	1.4				
Induced draft	1.2	1.2	...	1.4	...	...	...	...	1.4	...	1.4				
Mine fans	1.6	1.4	2.0	...	...	2.0	...	...	...	...	1.6				
Positive blowers	1.6	1.6	...	2.0	2.0	2.0	...	...	...	...	1.6				
Exhausters	1.2	1.2	...	1.4	...	...	...	...	1.4	...	...	...	...	1.5	1.5
Flour-feed-cereal—Mill machinery:															
Bolters and sifters	...	1.0													
Grinders and hammermills	...	1.4	...	...	...	...	...	...	...	...	1.6				
Purifiers and reels	1.2	1.4													
Main line-shaft drive	1.4	1.4	1.6	1.4	1.4	...	...	...	...	...	1.8				
Separator	1.0	1.0													
Roller mills	...	1.4													
Generator and exciters	1.2	...	...	...	...	...	...	...	1.2	...	2.0	...	...	1.4	1.4
Laundry machinery:															
Washers	1.2	...	...	...	...	...	...	...	...	1.2					
Extractors	1.2	...	...	...	...	...	...	...	...	1.2					
Tumblers	1.2	...	...	...	...	...	...	...	...	1.2					
Dampeners	1.2	...	...	...	...	...	...	...	...	1.2					
Flat work ironers	1.2	...	...	...	...	...	...	...	...	1.2					
Line shafts	1.4	1.4	...	1.4	1.4	2.0	1.4	1.4	1.4	1.4	1.6	...	...	1.6	1.6
Machine tools:															
Grinders	1.2	...	...	1.4	...	...	1.2	1.0	1.2	1.2					
Boring mills	1.2	...	...	1.4	...	...	...	...	1.2	1.2					
Lathes	1.0	...	...	1.2	...	...	1.0	1.0	1.0	1.0					
Milling machines	1.2	...	...	1.4	...	...	...	...	1.2	1.2					

TABLE 8. SERVICE FACTORS.—(*Continued*)

Applications	*Prime movers*														
	Electric motors										*Engines*				
	AC								*DC*		*Gas and diesel*			*Steam*	*Line shafts and clutch starting*
	Squirrel cage			*Wound rotor (slip-ring)*	*Synchronous*		*Single-phase*		*Shunt-wound*	*Com-pound-wound*	*4 or more cyl. above 700 rpm*	*4 or more cyl. below fact'y)*	*3 or less cyl. (refer to fact'y)*		
	Normal torque, line start	*Normal torque, compen-sator start*	*High torque*		*Normal torque*	*High torque*	*Repul-sion and split-phase*	*Ca-pacitor*							
Machine tools:—*Continued*															
Screw machines	1.0	...	...	1.0	...	...	1.0	1.0	1.0	1.0					
Cam cutters	1.0	...	...	1.0	...	...	...	...	1.0	1.0					
Planers	1.2	...	...	1.4	...	...	1.2	1.0	1.2	1.2					
Shapers	1.0	...	...	1.0	...	...	1.0	1.0	1.0	1.0					
Drill press	1.0	...	...	1.0	...	...	1.0	1.0	1.0	1.0					
Drop hammers	1.0	...	...	1.0	...	...	1.0	1.0	1.0	1.0					
Shears	1.2	...	...	1.4	...	...	1.2	1.2	1.2	1.0					
Mills:															
Pebble	...	1.4	1.6	1.4	...	...	...	...	...	1.4	..	...	...		1.6
Rod	...	1.4	1.6	1.4	...	...	...	...	...	1.4	...	...	...		1.6
Ball	...	1.4	1.6	1.4	...	...	...	...	...	1.4	...	...	...	...	1.6
Roller mills	...	1.4	1.6	1.4	...	...	...	...	...	1.4	...	...	...	...	1.6
Flaking mills	...	1.6	1.6	1.4	...	...	...	...	...	1.4	...	...	...	...	1.6
Tumbling barrels	...	1.6	1.6	1.4	...	...	...	...	...	1.4	...	...	...	...	1.6
Oil-field machinery:															
Slush pumps	...	...	...	...	...	...	...	...	1.4	...	1.4	1.6	...	1.4	1.4
Pumping units	1.2	1.2	1.4	...	...	...	...	...	1.4	...	...	...	...	...	1.6
Pipe line pumps—centrifugal	1.2	1.2	1.4	...	...	...	...	...	1.4	1.4					
Draw works (intermittent)	...	...	...	...	...	...	...	...	1.3	...	1.0	1.0			
Hoisting-service factor Based on total engine hp (Continuous rating) electric drive factor based on continuous rating of motor															
Paper machinery:															
Jordan engines	1.5	1.3	1.8	1.5	1.6	1.8	...	...	1.5	1.5					
Beaters	1.4	1.4	...	1.4	...	...	...	...	1.4	1.4	...	...	...	...	1.8
Calenders	1.2	1.2	...	1.2	...	...	...	...	1.2	1.2					
Agitators	1.2	1.0	1.4	1.2	...	...	...	...	1.2	1.2	...	...	...	...	1.6
Driers	1.2	1.2	...	1.2	...	...	...	...	1.2	1.2					
Paper machines	1.4	1.4	...	1.5	...	...	...	...	1.5	1.5	...	...	...	...	1.6
Printing machinery:															
Rotary press	1.2	1.2	...	1.2	...	...	...	...	1.2						
Embossing press	1.2	1.2	...	1.2	...	...	...	...	1.2	1.2					
Folders	1.2	1.2	...	1.2	...	...	...	...	1.2						
Paper cutters	1.2	1.2	...	1.2	...	...	...	...	1.2	1.2					
Linotype machines	1.2	1.2	...	...	...	...	...	...	1.2						
Flat bed press	1.2	1.2	...	1.2	...	...	...	...	1.2						
Pumps:															
Centrifugal	1.2	1.2	1.4	1.4	...	...	1.2	1.2							
Gear	1.2	1.2	1.4	1.4	...	...	1.2	1.2							
Rotary	1.2	1.2	1.4	1.4	...	...	1.2	1.2	1.2	...	1.2				
Reciprocating:															
3 or more cylinders	1.2	1.2	...	1.4	1.4	1.6	...	...	...	...	1.8	...	...	1.8	
1 or 2 cylinders	1.4	1.4	...	1.6	1.6	1.8	...	...	...	...	2.0	...	...	2.0	
Dredge pumps	1.4	1.4	...	1.4	...	...	...	...	...	...	2.0	...	...	2.0	
Rubber plant machinery:															
Calenders	1.4	1.4	1.4	1.4	...	1.8	...	...	...	...	...	...	...	2.0	
Banbury mills	1.4	1.4	1.4	1.4	...	1.8	...	...	...	...	...	...	...	2.0	
Mixers	1.4	1.4	1.4	1.4	...	1.8	...	...	...	...	...	...	...	2.0	
Screens:															
Vibrating	1.2	1.2	1.4												
Conical	1.2	1.2													
Revolving	1.2	1.2													
Textile machinery:															
Spinning frames	1.6	...	1.8												
Twisters	1.6	...	1.8												
Looms	1.2														
Warpers	1.2														
Reels	1.2														

to be driven, and multiply the rated (name-plate) horsepower of the driving unit by this factor.

In addition to the foregoing corrections, allowance should be made for other conditions that cause decreased pulley contact, such as the following: tapered cone drives; vertical drives with pulley underneath; tight side of belt on top; presence of excessive oil, water, or dust, or other condition that prevents clean, dry contact between belt and pulley. Such conditions, which may reduce the belt horsepower capacity by as much as one-half, cannot be judged mathematically, and allowance should be made for them on the basis of previous experience.

Determining Length of Drive

Length of open drive endless belts can be found to within about 0.15 per cent by using the formula

$$L = 2C + 1.57(D + d) + \frac{(D - d)^2}{4C}$$

where L = length of belt in feet
C = center distances between pulleys in feet
D = large pulley diameter in feet
d = small pulley diameter in feet

Determining Center Distance

The center distance of a flat belt on open drive can be calculated with the aid of the following formula, where the symbols have the same meaning as above:

$$C = X + \sqrt{X^2 - Y}$$

where $X = L/4 - 0.3925(D + d)$
$Y = 0.126(D - d)^2$

Although the length of an open drive can be calculated, it is desirable, whenever possible, to measure the actual belt length with a steel tape passed around the pulleys. The motor should be set at its minimum take-up position, so that maximum take-up capacity will be provided. Where there is a floating idler pulley, it should be in its normal position when the measurement is made.

CROSSED ENDLESS-BELT LENGTH. (1) First calculate the length L of an open-drive belt for the pulley diameters and center distance. (2) Calculate the added length required, with the formula

$$L_a = \frac{Dd}{C}$$

where L_a is the added belt length, and other symbols have the same meanings as in the formula for L. (3) Add L and L_a to obtain correct crossed-belt length.

BELT TENSION

A transmission belt must be made shorter by an amount sufficient to offset the increase in length caused by tension.

CUTTING BELTS TO LENGTH TO PROVIDE INITIAL TENSION. The common rule-of-thumb method of determining belt length when cutting is to deduct 1 per cent, or ⅛ inch per foot, of the belt length as determined by calculation or steel-tape measurement. Thus, for a drive where the tape measurement is 30 feet, the belt would be cut 29 feet 8¼ inches. There are variations that affect this rule, some of which are

1. Vertical drives: Increase allowance to $\frac{3}{16}$ inches per foot.
2. Belt speeds over 4,000 feet per minute: Increase allowance as for vertical drives.
3. Cord-type belts: Reduce allowance one-third (to $\frac{1}{12}$ inch).
4. Humidity: As humidity increases, rubber belts, like fabric ones, become shorter, while leather belts become longer.
5. Conditioning: A belt should be conditioned before installation by storing it from 2 days to 2 weeks in the room where it is to be used. Either unroll the belt or loosen the roll during this period. When the room conditions are either extremely moist or extremely dry, conditioning is doubly important. After conditioning, install, making usual allowance for initial belt tension. When making steel-tape measurement around pulleys, be sure motor is in its maximum position so that maximum amount of take-up is provided. If one of the pulleys is a floating or weighted idler, take the measurement with the idler in normal running position.

The Tables 9 and 10 of B. F. Goodrich belts will serve as examples of how tension varies and how much it affects belt length. The percentages in the body of each table are the amounts the steel-tape (or calculated) measurement of length should be varied.

Tension allowance for conditioned belts: Subtract from steel-tape measurements the percentages of length indicated.

TABLE 9. ALLOWANCE FOR TENSION WHEN CUTTING CONDITIONED BELTS

Type belt	*Load compared with rated belt horsepower capacity*			
	Under 50%	*50–75%*	*75–100%*	*Over 100%*
Multicord	½ of 1%	½ of 1%	¾ of 1%	1%
Highflex, Highflex, Jr.	¾ of 1%	1%	1%	1½%
Commander	1%	1½%	1½%	2%

Tension allowance for unconditioned belts that will be used where humidity is high: Add or subtract from steel-tape measurements the percentages of length indicated in Table 10.

TABLE 10. ALLOWANCE FOR TENSION WHEN CUTTING UNCONDITIONED BELTS TO BE USED WHERE HUMIDITY IS HIGH

Per cent rated capacity	*Under 50*			*50–75*			*75–100*			*Over 100*		
Total take-up of belt length, %	*1–2%*	*2–4%*	*Over 4%*	*1–2%*	*2–4%*	*Over 4%*	*1–2%*	*2–4%*	*Over 4%*	*1–2%*	*2–4%*	*Over 4%*
Type belt:												
Multicord	0	+½	+1	0	0	+½	0	0	0	0	0	0
Highflex, Highflex, Jr.	0	0	+½	0	0	0	−½	0	0	−¾	−½	0
Commander	0	0	0	−½	0	0	−1	−½	0	−1½	−¾	−½

Variations of Tables 9, 10:

1. Vertical drive (or within 10 per cent of vertical) with smaller pulley below: Make belt slightly shorter than tables indicate.

2. Belt speeds above 4,000 feet per minute: Make belt slightly shorter to create additional tension to offset centrifugal force.

3. Floating or weighted idlers: When the corrections indicated in Table 10 are made, the idler will ride at a lower position until the belt has shortened to correct length as a result of humidity.

BELT WEIGHT. The weight per foot of flat rubber belting varies with type and brand. The following tabulation of B. F. Goodrich belting may be considered as typical for belting of various manufacturers.

TABLE 11. WEIGHTS OF TRANSMISSION BELTS PER INCH OF WIDTH PER LINEAL FOOT

Highflex		*Highflex, Jr.*	
	Weight, lb		*Weight, lb*
3 ply	0 077	Light single	0 068
4 ply	0 104	Medium single	0 086
5 ply	0.133	Heavy single	0 104
6 ply	0.161	Light double	0 122
7 ply	0.188	Medium double	0 140
8 ply	0.216	Heavy double	0.158
9 ply	0.243		
10 ply	0.271		

Multicord

Thickness	*Under 8 in.*	*8–10 in. inclusive*	*10–28 in. inclusive*	*Over 28 in.*
Extra light	0 097	0 115		
Light	0 115	0.136	0.157	0.178
Medium	0 136	0.157	0.178	0 119
Heavy	0 157	0.178	0 199	0.220

BEARING LOADING

Modern rubber transmission belting has such strength and such low permanent elongation that tension can be increased to a point where horsepower greater than that calculated or determined from tables will be transmitted. However, such increase in tension should be made only when the belt splice and bearing assemblies will stand it.

BEARING PRESSURE. For 180-degree arc of contact, the pressure on pulley bearings caused by belt tension is equivalent to the sum of tensions in both strands of the belt. When a belt is operating at its rated horsepower, this tension sum does not exceed 35 pounds per ply for each inch of belt width. Thus a 12-inch, six-ply belt at 180-degree arc of contact and normal horsepower would exert a pull on pulley bearings of $6 \times 12 \times 35$, or 2,480 pounds. This load is divided between the two adjoining shaft bearings in inverse proportion to the distances of the bearings from the pulley. Thus the nearer bearing bears the greater portion of the load.

BEARING PRESSURE CAPACITY. This is the maximum capacity at which a perfect oil film will still be maintained. It is expressed in pounds

per square inch of the projected bearing area. This area equals shaft diameter times bearing length in inches. When bearing temperature exceeds 140°F, it indicates an imperfect oil film.

The following formula, based on investigations of F. W. Taylor on line-shaft bearings, chain or ring oil type, babbited surfaces, may be used as a general rule for calculating bearing pressure capacity:

$$P = \frac{90{,}000}{DR}$$

where P = allowable pressure in pounds per square inch of projected area
D = diameter of shaft in inches.
R = rpm

For exact pressure capacities of roll, ball, and other types of bearings, manufacturers' catalogues are the best guides

Belt Slippage. This is caused by (1) not enough arc of contact. Belt horsepower tables and formulas are based upon 180-degree wrap. The greater the arc the less the tendency to slip. (2) Low coefficient of friction between pulley and belt. Friction depends upon nature of belt and pulley surfaces. It is higher when belt and pulley surfaces are smooth than when rough and when belting is soft and pliable than when hard and stiff. Moisture, water, and dirt reduce friction. Thus the coefficient of friction is a somewhat elusive value, and in the same belt it may vary over different areas. Air between belt and pulley causes slip by reducing friction. (3) Insufficient force pressing the belt against the pulley. One of the chief causes of insufficient pressure is too much slack in the section of belt returning from driver to driven pulley. At speeds up to about 4,000 feet per minute, pressure is increased merely by making the belt tighter; but above that speed, centrifugal force, which increases as the square of the speed, takes a hand; and if the speed becomes high enough, the belt will slip badly and even fly off.

Increasing Belt Power Capacity. In view of the preceding conditions, belt capacity can be increased by such means as the following:

Increasing small-pulley arc of contact by (1) moving pulleys farther apart, (2) lengthening belt and forcing slack side down around pulleys by means of a swinging idler pulley.

Employing a high coefficient of friction by (1) selecting belt having high friction surface; (2) using pulleys that give higher coefficients, steel, paper, and wood being among the best; (3) applying belt dressing when drive is overloaded (normally, no dressing should be used on a rubber belt); (3) eliminating pocketing of air between belt and pulley by using a belt that is smooth, not too stiff, and adjusted so it does not vibrate or flap.

Maintain adequate slack-side tension by (1) having belt tight when originally installed. Shortening belt by cutting it 1/8 inch per foot less than actual steel-tape measurement around pulleys (see "Cutting Belts to Length") is usual way of assuring a tight belt. Actual initial tension, which is difficult to measure, should be 15 to 20 pounds per inch width per ply. (2) Increasing tension from time to time to offset that lost, by moving pulleys farther apart, shortening belt at splice, or using an automatic tightening device such as a weighted, swinging idler. Take-up adjustment is much preferable to belt-shortening. Best type of idler pulley is one having an adjustable weight that can be moved to regulate belt tension. (3) Using a belt having a low permanent stretch, such as a cord belt.

Determining Maximum Effective Pull. This is, strictly speaking, a laboratory job and is best left to the belt manufacturer. The difficulty of determining the various factors accounts for the variations that may be encountered in horsepower formulas and tables.

Some idea of the tension in a horizontal belt can be obtained by measuring its sag at rest. Table 12 shows the approximate sag of a belt like B. F. Goodrich Highflex when its tension is 15 to 20 pounds per inch per ply. The sag is the distance in inches between the upper strand of belting and a straight line joining the points where the upper belt surface leaves the supporting pulleys.

Table 12

Distance between Supports, Ft	*Approximate Sag, In.*
10	3/16- 1/4
12	1/4 - 5/16
15	3/8 - 1/2
18	5/16- 3/4
20	3/4 -1
25	1 -1 1/2
30	1 1/2 -2
35	2 -3

Belt Creep. Slip cannot be eliminated entirely from a flat transmission belt because of unavoidable creep. The smallest it can be made is 1 to 1 1/2 per cent, which represents the loss in speed shown by the driven pulley in comparison with the speed of the driver. Although a belt may transmit some power with a 5 per cent slip, good practice requires that the slip be kept to 1 or 2 per cent. Creep occurs because the belt actually changes length as it passes under tension around a pulley. Thus a section that is 10 inches long when it is under tension on the tight side may, when traveling on the slack side, measure 0.1 inch less, or 9.9 inches, The difference in length, or slip caused by creep, would then be 1 per cent.

Belt Drive Efficiency. When all other conditions are ideal, efficiency after allowing for unavoidable slip is close to 99 per cent.

Table 13. Tolerances in Endless Belts

Belt Length, Ft	*Tolerance, Plus or Minus*
Up to 10	1 in.
10–25	0.75%
35 and over	3 in.

Table 14. Typical Belt Thicknesses and Comparison with Leather Belts

Piles, heavy fabric belting	*Thickness, in.*	*Corresponding leather belting designation*
3	11/64	Light single
4	7/32	Medium single
5	9/32	Heavy single or light double
6	11/32	Medium double
7	25/64	Heavy double
8	29/64	Triple
9	1/2	

Length of Rubber Belting in Roll

To find length of flat rubber belting in a roll, use the following rule: Add the diameter of the center hole in inches to the diameter of the roll in inches, multiply the sum by the number of coils, and then multiply by 0.132.

Splicing Flat Transmission Belts

Rawhide Lacing. This is seldom used and is not recommended for rubber belting.

Metal Fasteners and Lacings. Follow manufacturer's directions for installing. Avoid use of oversize fasteners. Select fastener according to actual belt thickness, regardless of plies. Do not use plate fasteners on belt when there is an idler pulley. Wire-type fasteners cannot be countersunk readily in rubber belting. Inspect wire fasteners frequently for damage.

Cutting. Always use a steel square when cutting a belt end, regardless of the kind of fastener or splice that is to be used. When the belt is wide, lay out a center line for 10 feet or so from each end, and use this line as a guide for the square. Belt ends should be cut 90 degrees with respect to the center line.

Endless Belts. Modern belts having low permanent stretch often run for their entire lives without having to be shortened, but this is frequently true only when the take-up adjustment allows for a total belt stretch of 2 per cent. An endless-belt splice is 2 to 3 times as strong as a joint formed by a metal fastener.

Plylock Belt Joint

The B. F. Goodrich Plylock process is used to make belts endless, either in the factory or in the purchaser's plant. Ends of the belt plies are interlocked and countersunk beneath the surface of the belt by the removal of a short section of fabric in the second ply. The resulting depression is filled with a reinforced rubber cushion, and the entire joint permanently vulcanized in position. Portable vulcanizers have been developed for this purpose. The belt thickness remains absolutely uniform throughout, and the joint is as flexible as the remainder of the belt. There are no breaks, projections, metal fasteners, or other objectionable features. Strength of the joint runs 75 to 85 per cent of total belt strength.

Before the Plylock joint method was developed, flat transmission belts were spliced endless with a straight step splice. This is still an accepted method where the Plylock joint is not used.

Cleaning Rubber Belts

For removal of ordinary dirt, use water and soap or trisodium phosphate. For removal of greasy accumulations, a dry-cleaning fluid may be required. Use one that does not create a fire hazard. A suitable mixture is carbon tetrachloride, 60 parts, and high-test gasoline, 40 parts. Because of fumes, use only in limited quantities or where ventilation is good. Another cleaner, safe up to 120°F and in presence of static, is made by mixing ethyl (grain) alcohol and carbon tetrachloride in equal parts.

Dressings for Rubber Belting

Unlike leather, rubber belting does not have to be lubricated. Anything that penetrates the rubber surface will damage the belting. No dressing should have to be applied under normal conditions, except during a "break-in" period after being installed, when the rubber surface is being worn down to a point where it transmits power smoothly. During this period or at any other time when the belt becomes glazed as a result of slippage, a vegetable oil such as tung, castor, or boiled linseed or a special dressing made by a belting manufacturer can be applied.

Dressings containing rosin are likely to damage rubber; but when other measures fail to produce desired results, a plastic-stick-type rubber-belt dressing, containing rosin and agents that prevent damage to the rubber, may be applied.

Flat rubber transmission belts are repaired as described for conveyor belts (page 172).

New Belts from Old

Foldless or "raw edge" rubber belts, after being damaged or badly worn, often can be cut down for use on smaller drives. The belting is cut into narrower widths, and its thickness reduced by stripping off outer plies. Cut edges should be painted with a penetrating rubber cement to protect the fabric. Here is the outline of a typical belt-salvaging job where two seven-ply, 10-inch belts and one seven-ply, 12-inch belt were made into the following five-ply belts:

One 3½-inch open end.
One 4-inch open end.
One 3½-inch endless.
Two 6-inch endless.
One 8-inch endless.

The salvaged belting, ranging from 21 to 26 feet in length, saved $104.65 that would have been required for new belting.

Transmission-belt Troubles

Belt Runs off Pulleys. This may be caused by

1. Misalignment of pulleys.
2. Crooked belt joint because belt ends were not cut square.
3. Belt dressing building up on pulley to form artificial crown.
4. Belt becoming crooked from running over pulley edges.
5. Rubber along one edge being softened by oil.

Plys Separate. This is caused by

1. Pulleys too small (see Table 2, page 123).
2. Metal fasteners too large for pulley diameter being used.
3. Bumps on pulleys, usually caused by use of belt dressing and presence of dust that mixes with dressing.
4. Spread of blister caused by trapped air. Sometimes an air pocket in a belt can be eliminated by making lengthwise slit with knife to release air, and belt will operate for a long time without further ply separation.

Fasteners Pull Loose. This is caused by

1. Belt ends not even or square, causing uneven stress on fastener prongs.

2. Fastener of wrong size or type. Follow manufacturer's recommendations about size. Do not use leather-belt fastener for rubber belt.

3. Fasteners failing because of wear, particularly on side in contact with pulley.

4. Fastener strained by forcing belt to run over edges of pulleys when installing it. For belts over 8 inches wide, use belt clamps to pull ends together or ease take-up adjustment to permit belt to slide into place easily.

5. Belt tension too great.

6. Misalignment of pulleys.

7. Bumps on pulleys.

8. Use of idlers and reverse-bend pulleys.

9. Excessive number of punch holes in laced belt. An awl is preferable to a punch for making holes.

10. Too much pulley crown, particularly when belt is tight.

Note: Practically all the foregoing fastener troubles can be minimized or eliminated by use of vulcanized splice.

Belt Slips Excessively. This is evidenced by glazed inside surface of belt, high polish on pulleys, and more than 2 per cent difference in relative rpm of driver and driven shafts. Its causes are the following:

1. Belt too loose.
2. Belt and pulleys dirty.
3. Belt too light or having too much stretch.
4. Lack of idler pulley.
5. Incorrect drive design.

Among the remedies are (1) the use of belt dressing, which affords only temporary relief, and (2) the use of rubber lagging on pulleys, particularly the driver. Such lagging is applied by the Vulcalock process that bonds it securely to the metal.

Belt Breaks Crosswise. This rare failure may be caused by a drive having so many pulleys that belt cannot slip when overloaded, or by some other condition that prevents such slippage.

Belt Rips Lengthwise. Causes are as follows:

1. In a belt spliced by lacing or metal fasteners, failure of fastener may cause ripping. Sometimes protruding belt corner catches on an obstruction.

2. Letting a foreign object come into contact with belt.

3. Belt shifter catches fastener.

4. Belt runs over edge of pulley.

Seams Come Open. (Folded fabric belt): Causes are as follows:

1. Excessive pulley crown. Seam, normally run outside, should be run next to pulley when crown is great.

2. Oil disintegrates rubber along seam.

BELT STRETCHES EXCESSIVELY. Causes are as follows:

1. Unavoidable difference in stretch between belts made from different rolls of belting.
2. Too narrow margin between load and horsepower rating of belt.
3. Not enough plies.

Note: Sometimes if belt is continued in use, its tendency to stretch excessively will disappear. Cord belts should be used where fabric belts give persistent trouble by stretching.

INSIDE PLY WEAR. Wearing of inside ply may be caused or accelerated by

1. Excessive slipping.
2. Use of belt dressing, particularly that containing rosin or oil.
3. Presence of dust and dirt.

RAPID EDGE WEAR. Causes are as follows:

1. Using folded belt with automatic fork shifter.
2. Flanged pulleys out of line.
3. Misalignment of stepped cone pulleys. Belt rubbing against guides on cone pulley drives.
4. Oil on belt edge.

Note: Sometimes edge wear does not affect belt performance appreciably unless prolonged or occuring in presence of oil.

STATIC ELECTRICITY. Friction between belt and pulleys often causes static electrical charges to build up on belt. Potentials reached may endanger personnel or become a fire hazard when inflammable or explosive materials are present. Remedies include

1. Arrangement of a metal bar so that light brass chains can dangle from it and touch surface of belt. Connect bar to a ground (such as a water pipe) with a copper wire, preferably stranded, and not necessarily insulated.
2. Use of static-conductive rubber belts (see V-belts).

TYPICAL FLAT BELT DRIVES (see Fig. 3)

1. Open horizontal, tight side on bottom. Most efficient type.
2. Open horizontal, tight side on top. Requires larger cross section of belting than No. 1.
3. Semivertical open, tight side on top.
4. Semivertical open, tight side on bottom.
5. Semivertical crossed, small pulley below.
6. Semivertical crossed, small pulley above.
7. Vertical open, small pulley above.
8. Vertical open, small pulley below.

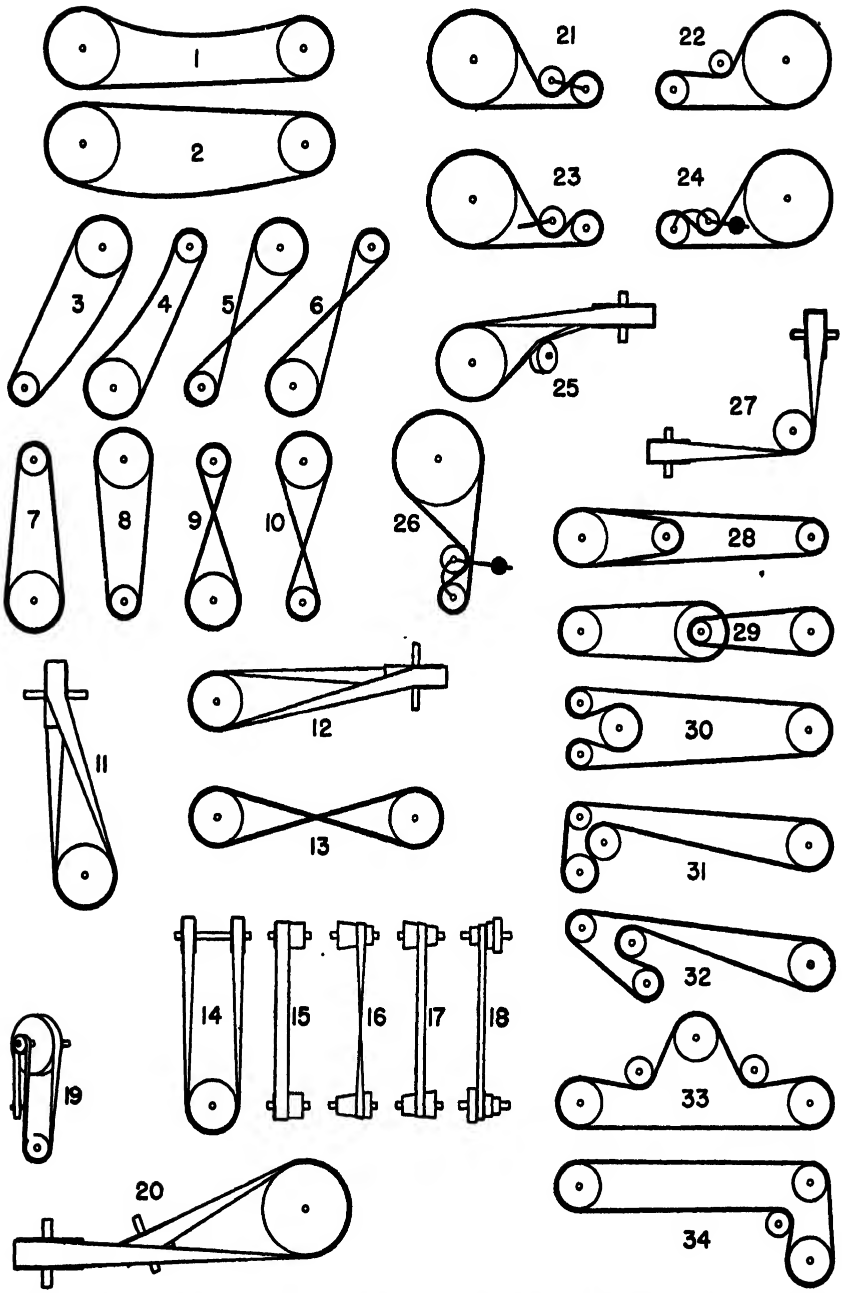


FIG. 3. Various ways of arranging flat-belt drives. Some of these arrangements may be used for V-belts.

9. Vertical crossed, small pulley above.

10. Vertical crossed, small pulley below.

11 and 12. Two-pulley quarter turn. Tight side forms 90-degree angle with driver and driven shafts. Not suitable for wide belts. Power loss considerable.

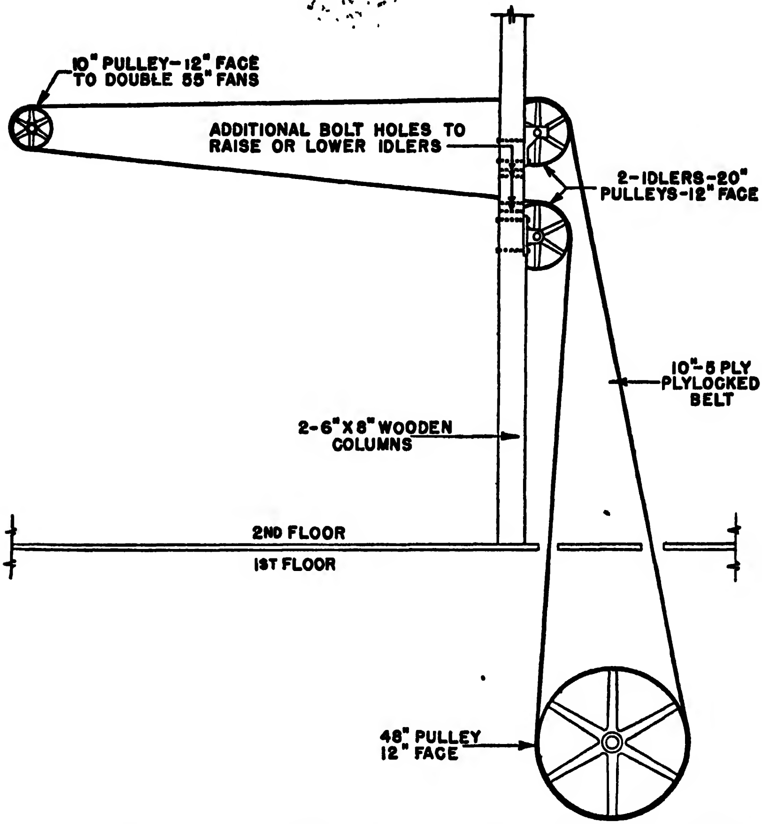


Fig. 4. A flat-belt drive for operating two large fans. Belt speed is 3,800 feet per minute, horsepower is 75. When a laced belt was used, the lacing had to be replaced and the belt taken up every 15 days. When a rubber belt, spliced to make it endless, was installed, such periodic attention became unnecessary.

13. Crossed horizontal or half-turn drive.

14. Four-pulley quarter turn. Each pulley turns in direction opposite to pulley parallel to it (see No. 19).

15. Common shifter drive with tight and loose pulleys. Shifting fork causes edge wear on belt.

16 and 17. Tapered-cone pulley drive, for controlling driven speed closely. Restricted to narrow, usually thick belts.

18. Stepped-cone pulley drive.

19. Four-pulley quarter turn, with upper pulleys turning in different directions at different speeds (see No. 14).

20. Three-pulley quarter turn (see No. 25).

21, 22, 23, and 24. Short-center drives. Numbers 24 and 26 show an adjustable-weight idler. Numbers 21 and 23 show a hinged idler. Number 22 shows an idler incorrectly placed; it should be nearer small pulley in order to increase arc of contact around that pulley.

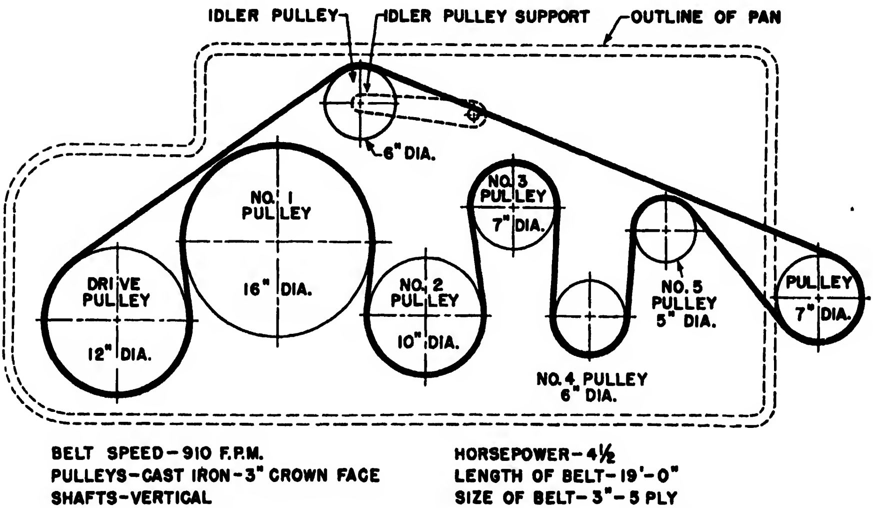


FIG. 5. Flat-belt drives can be complicated, as is this one on a wire-drawing machine. When a rubber belt with a Plylock splice was installed, it lasted twice as long as the best belt previously used, and the average production of the machine was increased 108 per cent.

25. Three-pulley quarter turn, with idler guide pulley near small pulley (see No. 20).

26. Short-center vertical drive, with idler having adjustable weight (see No. 24).

27. Mule drive, having four pulleys, used when the two shafts are located so driver and driven pulleys cannot be in line. Sometimes additional pulleys support edge of belt to prevent it from slipping off vertical mule pulleys until belt can be tightened.

28. Tandem drive, permitting one power source to operate two shafts or two power sources to be concentrated on one shaft. Unequal belt tension may cause loss of efficiency.

29. Series drive, in which second driver pulley is on same shaft as first driven pulley.

30, 31, and 32. Arrangements for rotating driven pulley in direction opposite that of driver pulley. Number 30 is poor because the small idler pulleys must bear full strain.

33 and 34. Two of many possible combinations for multiple drives involving three or more driver or driven pulleys.

Chapter 7

FLAT RUBBER BELTING—CONVEYOR

Rubber conveyor belts, used for carrying grain, sand, slag, ore, coal, ice, packaged goods, and other materials from one point to another, may be classified into several groups. Elevator belts, working at steep angles including the vertical, are really conveyor belts with buckets attached. The earliest form of belt conveyor was simply a flat belt running in a trough. Improvements have produced a conveying device that will handle heavy loads cheaply at high speeds over long distances.

FIG. 1. Cross section of conveyor belting showing customary location of seams in a 6-ply folded belt 36 inches wide. There are at least two seams per folded ply. The two middle plies are not folded.

FABRIC CONVEYOR BELT. Plies are of rubber-impregnated cotton duck sandwiched between thin layers of rubber compound and completely enclosed by a rubber cover. When the fabric is folded to make a flattened tube, there is one longitudinal seam for each two plies in belts up to 26 inches wide, two seams in wider belts. When the plies are not folded back at the belt edges, widths up to 72 inches can be made without longitudinal seams. Edges of the fabric are enclosed in a strip of breaker fabric and tie gum that unites the ply edges, skim coat rubber (between plies), and the rubber cover.

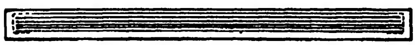


FIG. 2. Cross section of conveyor belting showing improved construction in which there are no seams in outside plies and rarely in inside plies up to 60-inch belt width.

CORD CONVEYOR BELT. For severe service such as high resistance to impact, cord-type conveyor belting is superior. In a typical belt of this type, the central plies are composed of textile cords running lengthwise. On the bottom (pulley side) of this central core are usually two fabric plies; and on the top, a ply consisting of transverse cords. The plies are bonded by rubber into a unit, and the outer covering is applied as in the all-fabric belt. The use of cord plies alone would produce a belt that is too flexible crosswise. A cord belt has higher flexibility and lower stretch than an all-fabric one. It troughs naturally and resists heavy impacts.

Steel-cord Conveyor Belt. Conveyor belts of lengths and lifts far exceeding anything formerly possible have been made available to industry as the result of development of a steel-cord construction. This type of belting is similar to some types of textile cord belting, except that a single ply of flexible, high-strength, steel aircraft cable takes the place of multiple layers of cord. The base of a typical steel-cord belt consists of two plies of 42-ounce duck with synthetic fiber filling, and the top cover gauge incorporates transverse breaker cords. Steel-cord conveyor systems simplify long-tunnel and similar installations by eliminating transfers.

Turnable Conveyor Belt. Designed for use in coke wharf service, the turnable conveyor belt has a ply construction that permits one half of the rubber cover to be made thicker than the other half of the cover on the same surface. The opposite surface of the belting is made in the same way, the thicker cover being opposite the thinner cover of the first surface. The coke, during loading, strikes the half of the belt having the thicker cover. When this cover has become worn, the belt is turned over so the thick-cover portion of the other surface will receive the load. Thus one belt has two lives.

Special Channel Conveyor Belt. This type is designed for mines where limited head room prevents use of troughing idlers. The belt has square, bare duck edges and a 3-inch exposed strip of duck along each bottom edge to reduce friction while passing through the steel channel in which the belt operates. Duck outwears rubber in such service. This belt works well on spool-type idlers.

Stepped-ply Conveyor Belt. This belt is intended for use where wear is severe in the middle of the belt, as in handling coke, abrasive ore, limestone, slag, and cullet. It has additional plies in the middle. In figuring belt strength, ply count is made in the middle, because tension is maximum there as result of pulley crowning. For handling heavy and abrasive materials, a straight-ply belt having a cover thicker in the middle is usually more satisfactory than a stepped-ply belt.

Hot-material Conveyor Belts. Ordinary conveyor belting will withstand temperatures up to 150°F, although anything over 125° is likely to shorten the life of the rubber. Hot-material conveyor belts are made with a special American-rubber compound that will withstand greater heat than crude rubber. Recommendations for heat conditions may be summarized as follows:

Table 1

Material Handled	*Max. Temp., °F*
Hot fines, ashes, etc., that form a hot blanket	225
Crushed coke and other lumpy materials	250
Any material, when belt is operating in hot chamber	200*

* Maximum temperature for both chamber and material.

Automatic stirring devices sometimes can be installed to hasten cooling of hot, fine material and thus provide added belt protection. Even though the cover and skim coat rubber may withstand greater heat than indicated above, limitations are imposed by the cotton fabric which starts to char at about 300°F.

Special Surface Belts. The top surface of a conveyor belt is normally coated with smooth rubber designed to resist abrasion, cutting,

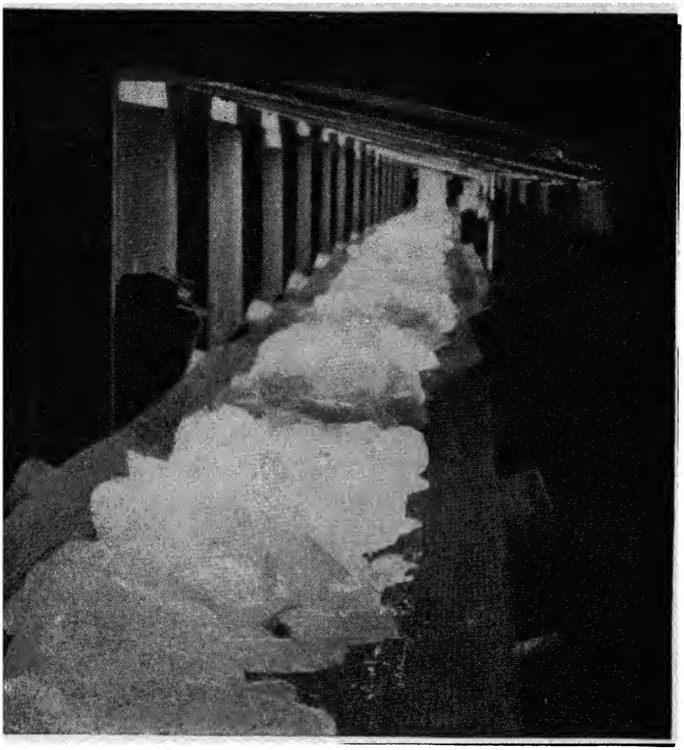


Fig. 3. A conveyor belt designed to do a special job. Three thousand rubber fingers per square yard hold slippery ice while carrying it up a seven per cent incline.

and tearing. When oil is to be encountered, as in the conveying of oil treated coal, oil-resisting rubber may be advisable in some cases, even though higher in cost. The belt surface may be textured to grip the load better. Thus, for conveying ice, the surface may be studded with thousands of little rubber fingers. Package-conveyor belts, operating on inclines up to 35 degrees, are provided with the same kind of gripping surface. Some applications, such as baked-goods handling, require a belt having a bare duck surface. Sliced-fruit conveyors use a belt whose rubber cover has a duck-impression surface.

Ply Thickness

Average ply thickness in conveyor belts is $\frac{1}{16}$ inch. Cord belts that are not of conventional ply construction may be listed as being equivalent to heavy fabric belts of so many plies.

Specifying New Replacement Conveyor Belts

When planning to replace an old conveyor belt, consideration should be given to various factors that may permit a better installation than the original.

Grades. Recent manufacturers' literature should be examined to determine the different available grades of belts. The chief differences among grades lie in the quality of the rubber friction that impregnates and unites the cotton cords or plies and in the quality of the rubber covers.

Before the Second World War, friction quality was indicated by the pounds pull per inch of width required to separate two adjacent plies. Cover quality was indicated by the tensile strength of the rubber compound in pounds per square inch. These values were useful only for comparing grades and were not a measure of service performance to be expected. Tensile strength is relatively meaningless as a measure of service strength, because a conveyor belt is scarcely stretched at all. Tensile strength was a fairly good indication of cutting and abrasion resistance of crude rubber belting compounds. For American-rubber compounds, this is not true, and so intercomparison is not feasible. Thus, a GR-S belt having a tensile strength of 2,000 pounds may wear twice as well as a crude-rubber belt having the same tensile strength.

Some comparisons of crude- and American-rubber conveyor belting are as follows:

American-rubber belts require heavier covers than crude-rubber types. For ordinary service, the increase is 25 per cent; for severe service, 33 to 50 per cent.

Neoprene type (GR-M) rubber is superior to GR-S with respect to oil and flame resistance. Although laboratory tests indicate also a superiority with respect to gouging, cutting, and abrasive wear, this advantage does not carry over into actual practice.

Covers. When material being handled is composed of small particles that do not impose severe blows upon the belt, it may be possible to specify a thinner belt cover. If the old belt was not worn badly in the middle, a thinner cover is probably logical. But if belt wear was severe in the middle, cover thickness should be increased.

TABLE 2. COVER THICKNESSES COMMONLY USED

	Inch
Top covers:	
Light service, such as grain conveying	$\frac{1}{32}$ min.
Average service	$\frac{1}{8}$
Severe service	$\frac{3}{8}$
Back covers:	
Favorable conditions	$\frac{1}{32}$
Average conditions	$\frac{1}{16}$
Severe conditions	Up to $\frac{1}{8}$

Wearing away of the back cover of an old belt indicates that it was slipping on the pulleys. When belt tension is high, use of a very thick back cover may lead to excessive creeping and blistering (see also Special Surface Belts, page 153).

DUCK REINFORCEMENT. When an old belt is excessively stretched, the replacement belt should be ordered with more plies or with heavier duck. When belt tension is very low, money sometimes can be saved by using a lighter duck or fewer plies.

WHAT THE MANUFACTURER SHOULD KNOW. When asking manufacturers for specific information concerning a conveyor installation, include a sketch of the conveyor layout and as much data as possible concerning the points listed below. The manufacturer's engineers can then make more intelligent recommendations.

Belt width, center-to-center length of conveyor, elevation difference between loading and discharging points; whether drive is simple, snub pulley, dual motor, or tandem.

Arc of contact. If tandem or dual motor drive, show drive location relative to head pulley.

Sizes of driving and tail pulleys, types of idlers and bearings, idler spacing, idlers per carrier, lubrication method.

Material handled, whether wet or dry, material temperature, maximum size of particles.

Horsepower of drive and horsepower consumed, average tons-per-hour delivery (specify long or short tons), peak delivery in tons per hour, speed, average hours per day operation.

Type of feed, chute arrangement, whether conveyor is housed or in open, number of fixed or traveling loading trippers, kind of take-up and number of feet it permits belt to stretch, weight if gravity takeup is used.

Description of previous belt, including its grade, plies, covers, tonnage carried, and causes of its failure.

CONVEYOR-BELT DESIGN

Factors involved in selecting a conveyor belt include (1) horsepower needed to operate the system, (2) weight of duck in a fabric belt, (3) num-

ber of plies, (4) quality of rubber friction between plies, (5) cover quality and thickness, (6) unusual operating requirements and (7) length, speed, capacity, lift, and similar variables, some of which are involved in determining one or more of the preceding factors.

HORSEPOWER OF CONVEYOR. Determining the horsepower of a belt conveyor involves five factors:

1. Horsepower needed to move the *empty belt*, represented by X. The formula for this is

$$X = \frac{G \times F_x \times S \times L_c}{33{,}000}$$

2. Horsepower needed to move the *load* horizontally, represented by Y. The formula is

$$Y = \frac{L_c \times F_y \times C}{990}$$

3. Horsepower required to elevate or lower the load, represented by Z. When the conveyor is running down hill, Z is negative. The formula is

$$Z = \frac{H \times C}{990}$$

4. Horsepower required to operate tripper and accessories, as shown in Table 8.

5. Horsepower loss in driving mechanism, as shown in Table 9.

The horsepower that should be transmitted by the drive pulley to the belt is the algebraic sum of X, Y, Z, plus variations indicated in Tables 8 and 9. In the above formulas, the symbols are as follows:

G = weight per foot in pounds, of the conveyor belting, idlers, snub pulleys, and any terminal pulleys turned by the belt. This value is on the basis of weight per foot of conveyor, measured along the belt between terminal pulley centers (see Table 5)

F = coefficient of rotational friction of rolling parts such as pulleys and idlers

F_x = value of F to be used when considering the power required to move the empty belt (see Table 6)

F_y = value of F to be used when considering the power required to move the load horizontally (see Table 6)

S = belt speed in feet per minute (see Table 7 showing maximum recommended belt speeds)

L = conveyor length in feet, measured along the belt between centers of terminal pulleys. Strictly speaking, the L used in the Y formula should be the horizontal center length. But unless the center dis-

tance is very great and there is a high lift, the center length measured along the belt is accurate enough

L_c = the corrected center length, as shown in Table 14

$$L_c = L + (115 - 0.45L)$$

H = vertical distance in feet between centers of the head and tail (terminal) pulleys (Table 15)

C = conveyor capacity per hour at operating speed, in short tons (2,000 pounds). Use the maximum belt capacity or rate of feed that is possible with the operating speed to be used unless a lower rate is absolutely controlled. Table 16, showing weight of various materials per cubic foot, and Table 11, showing sizes of lumps that various width belts will handle, will be helpful in determining C.

CORRECTING CALCULATED HORSEPOWER. The algebraic sum $X + Y + Z$ is the total computed horsepower for the drive. It is necessary to correct the horsepower by adding the power required for operating trippers (see Table 8).

When selecting a conveyor drive motor, its power should be enough to provide also for power loss in the driving mechanism and in the motor itself (see Table 9). Thus the total horsepower of the conveyor and therefore the required power of the motor are $X + Y + Z +$ tripper correction + power-loss correction. This total horsepower requirement can be represented by P.

BELTING STRESS

Maximum stress T_1, in a conveyor belt, can be computed after the total horsepower P has been determined. Centrifugal tension in a conveyor belt is negligible and can be disregarded in this calculation. The standard formula for power transmission belting is used:

$$T_1 - T_2 = \frac{33{,}000P}{S}$$

or

$$T_1 - T_2 = E$$

or

$$T_1 = EK + E$$

where T_1 = tension in tight side of belt in pounds
T_2 = tension in slack side of belt in pounds
S = belt speed in feet per minute
E = effective tension in pounds
K = drive factor, as shown in Table 12

This factor is determined by the arc of contact between belting and drive pulley or pulleys and the coefficient of friction between belting and pulley.

T_1 CORRECTION. When driving pulleys are located a considerable distance from the head pulley, T_1 may have to be increased. Amount of increase = weight of the belting per foot, in pounds, × vertical distance, in feet, between the drive and head pulley centers.

NUMBER OF BELTING PLIES

To determine the number of belting plies required to withstand maximum tension, for fabric or cord belts through the No. 100 cord construction, first calculate the belt working tension in pounds per inch of belt width by using the formula

$$\text{Working tension} = \frac{T_1}{\text{belt width, in in.}}$$

where T_1 is the maximum tension existing in the belt when running at operating speed and load.

To determine the number of belt plies necessary to handle the calculated tension when vulcanized splices are used, refer to Table 3 for selection of plies for conveyor belts.

In Table 3, find the belt working tension in pounds per inch of belt width, and opposite it read the correct number of plies for a fabric or textile cord belt or the correct class number for a steel-cord belt.

When metal fasteners are used on 28-, 32-, 36-, or 42-ounce fabric belts, the working tension in pounds per inch of belt width, as calculated above, must be multiplied by 1.2 and the resulting tension figure used in selecting the proper belt from the table. When such fasteners are used on the No. 50 cord belt, multiply by 1.25 to obtain the corrected tension.

Table 3 also shows minimum belt width that will trough satisfactorily when belt is running empty or lightly loaded.

PERMISSIBLE WORKING STRESSES. Table 4, showing permissible working stresses for various belting materials and constructions, is based on actual strength of materials plus a suitable safety factor.

TROUGHING AND PLY NUMBER. To operate properly, a conveyor belt must, when running empty, conform to the shape of the idlers. Such troughing is determined by the number of plies. A belt that has too many plies will not curve enough to make good contact with idlers and therefore will not run straight. On the other hand, the number of plies

Table 3. Conveyor-belt Tension

Maximum working tension — lb per inch of belt width	28 oz.		32 oz.		36 oz.		42 oz.	42 oz & #50 cord	#50 cord	#70 cord		#100 cord		Steel cord	
	No of plies & minimum troughing width	Max. tension range — lb per in of width	No of plies & minimum troughing width	Max. tension range — lb per in of width	No of plies & minimum troughing width	Max. tension range — lb per in of width	No of plies & minimum troughing width	Max. tension range — lb per in of width	No of plies & minimum troughing width	No of plies & minimum troughing width	Max. tension range — lb per in of width	No of plies & minimum troughing width	Max. tension range — lb per in of width	Class & minimum troughing width	Max. tension range — lb per in of width
75	3P 12" MI		3P 12" MI		3P 18" MI										
		93													
100															
	4P 18" MI			108		123									
125			4P 18" MI												
		127		148	4P 24" MI		3P 24" MI		3P 12" MI						
150	5P 24" MI							150							
		161	5P 24" MI			168									
175	6P 30" MI						4P 30" MI		4P 18" MI						
		192		187	5P 30" MI										
200	7P 36" MI		6P 30" MI												
		223		223		213		206							
225	8P 36" MI														
			7P 36" MI		6P 36" MI		5P 36" MI		5P 18" MI						
250															
		257		259		254		258							
275			8P 36" MI		7P 36" MI										
				299		295	6P 12" MI		6P 24" MI						
300			9P 42" MI		8P 42" MI										
				315		340		309		5P 18" MI					
350					9P 42" MI		7P 48" MI		7P 24" MI		350				
						381		361		6P 24" MI					
400					10P 48" MI		8P 48" MI		8P 30" MI						
						422		412			432				
450							9P 54" MI		9P 30" MI			5P 18" MI			
								464		7P 24" MI			457		
500							10P 54" MI		10P 36" MI						
								515			512	6P 24" MI			
550										8P 30" MI					
											592		573		
600										9P 36" MI		7P 24" MI			
											672		688		
700										10P 42" MI					
											752	8P 30" MI			
800															
													804		
900												9P 36" MI			
													918	1000 24" MI	
1000												10P 42" MI			1000
													1032	1500 24" MI	
1500															1500
														2000 24" MI	
2000															2000
														2500 24" MI	
2500															2500
														3000 24" MI	
3000															3000

TABLE 4. NOMINAL WORKING STRESSES

Belt duck	Stress, lb/in./ply	
	Vulcanized splices	Metal fasteners
28-oz	31	26
32-oz	36	30
36-oz	41	35
42-oz	50	43
No. 50 cord	50	40
No. 70 cord	70	40
No. 100 cord	100	40
Steel cord	**Stress, lb/in. of belt width**	
No. 1,000	1,000	
No. 1,500	1,500	
No. 2,000	2,000	
No. 2,500	2,500	
No. 3,000	3,000	

must not be so low that the belt will not retain stability when loaded. Some general suggestions are listed:

For grain-carrying belts: Minimum of four plies of 32-ounce duck, maximum of six plies up to belt widths of 60 inches.

For belts over 30 inches wide: Use at least 32-ounce fabric.

TABLE 5. VALUES OF G FOR VARIOUS BELT WIDTHS AND TYPES OF SERVICE
Numbers indicate weight per foot in pounds.

Belt width, in.	Grain conveyors	Standard conveyors	Heavy-duty conveyors
14	9	14	
16	10	16	
18	11	17	
20	12	19	
24	15	22	32
30	18	26	45
36	21	32	58
42	24	45	71
48	29	52	84
54	35	61	97
60	38	71	110

TABLE 6. VALUES OF F_x AND F_y*
Determined by studying actual conveyor belt installations.

Type of bearings and condition of conveyor	F_x	F_y
Most ideal†	0.025	0.030
High grade	0.030	0.040
Average. To be used if no details are known except that antifriction idlers are used (ball or roller bearing)	0.035	0.050
Plain bearings, such as those on old systems	0.050	0.075

* In cold weather, the values of F_x and F_y are slightly higher.
† Use of the "most ideal" values is rarely justified.

TABLE 7. VALUES OF S, THE RECOMMENDED MAXIMUM BELT SPEEDS
In feet per minute, for conveyor belts of various widths.

Material handled	*Belt widths, in.*										
	14	*16*	*18*	*20*	*24*	*30*	*36*	*42*	*48*	*54*	*60*
Light, free-flowing	300	300	400	400	500	600	600	600	700	700	700
Coal and similar lump material	300	300	400	400	500	550	550	600	600	650	650
Heavy ore and other abrasive material	300	300	350	350	450	550	550	550	600	600	600

TABLE 8. HORSEPOWER REQUIRED TO OPERATE TRIPPERS

Belt width, in.	*12*	*14*	*18*	*20*	*24*	*30*	*36*	*42*	*48*	*54*	*60*
Hp to add for fixed or hand-propelled tripper	0.40	0.70	1.00	1.35	1.75	2.50	3.25	4.50	6.00	7.50	9.00
Hp to add for self-propelling tripper	0.44	0.77	1.10	1.50	1.90	2.75	3.55	5.00	7.00	8.00	10.00

TABLE 9. HORSEPOWER CORRECTION FOR DRIVE OR SPEED-REDUCTION UNIT*

Cast tooth gears	*Cut tooth gears, roller chain or belting*	*Self-contained spur or helical gear speed reducer*
Add 10% for each reduction	Add 5% for each reduction	Add 5%

* When using worm gear reducers, be sure to use manufacturers' efficiency ratings.

Table 10 shows the maximum and minimum number of plies that permit good troughing on three-pulley, 20-degree side idlers.

There are some other factors that may influence conveyor belt selection. Several of these are summarized in Table 13, which shows capacities for conveyors on standard 20-degree troughing carriers.

TABLE 10. MAXIMUM PLIES FOR TROUGHING

Belt width, in.	*28 32 oz.*	*36 oz.*	*42 oz.*	*Cord No. 50*	*Cord No. 70 No. 100*
12	3	..	..	3	
18	4	..	..	5	
24	5	4	3	7	6
30	6	5	4	9	8
36	7	6	5	10	9
42	9	8	6	10	10
48	..	10	8	10	10
54	..	..	10	10	10
60	..	..	10	10	10

Tables 5, 6, and 7 show values for various symbols used in the calculation of conveyor power.

TABLE 11. MINIMUM PLIES TO SUPPORT LOAD

Belt width, in.	*Light free-flowing material*		*Fine coal or crushed stone up to 3 in. size*					*Lump coal and similar material*					*Heavy ore and similar material*			
	28 oz.	*32 oz.*	*28 oz.*	*32 oz.*	*36 oz.*	*42 oz.*	*Cord No. 50 No. 70 No. 100*	*28 oz.*	*32 oz.*	*36 oz.*	*42 oz.*	*Cord No. 50 No. 70 No. 100*	*32 oz.*	*36 oz.*	*42 oz.*	*Cord No. 50 No. 70 No. 100*
12	3	3	..	.	..		3									
18	4	4	4	4	4	.	4	4	4	4	..	4				
24	4	4	4	4	4	3	4	4	4	4	..	4	5	4	.	5
30	4	4	5	5	5	4	4	5	5	5	4	4	6	6	4	5
36	4	4	6	5	5	4	4	6	6	6	4	5	7	6	5	5
42	4	4	6	5	5	5	5	7	7	6	5	6	8	7	6	6
48	4	4	6	5	5	5	5	8	7	7	5	6	8	7	7	7
54	..	..	.	7	6	6	6	.	8	7	6	6	.	..	8	8
60	..	..	..	7	7	6	6	.	8	7	6	6		.	8	8

VALUES OF G. The value of G should be calculated when convenient or possible, especially when the job is large or otherwise important. Weight of the belt, idlers, and pulleys must be known. Divide the total weight of these elements by the length of the conveyor in feet.

TABLE 12. VALUE OF DRIVE FACTOR K

Angle of belt wrap at drive, deg*	Type of drive	Drive factor (K) The following constants multiplied by the effective tension (T_E) equal slack side tension (T_2)			
		Screw take-up		Gravity weighted or flexible take-up	
		Bare pulley	Lagged pulley	Bare pulley	Lagged pulley
180	Plain	1.6	1.0	0.84	0.5
190	Snubbed	1.5	0.9	0.77	0.45
200	Snubbed	1.4	0 8	0.72	0.42
210	Snubbed	1.3	0.7	0 67	0.38
220	Snubbed	1 2	0.6	0 62	0.35
230	Snubbed	Not recommended	Not recommended	0.58	0.32
240	Snubbed	Not recommended	Not recommended	0.54	0.30
360	Tandem	Not recommended	Not recommended	0.26	0.125
380	Tandem	Not recommended	Not recommended	0.23	0.113
400	Tandem	Not recommended	Not recommended	0.21	0.095
420	Tandem	Not recommended	Not recommended	0.19	0.084
440	Tandem	Not recommended	Not recommended	0.17	0.074
460	Tandem	Not recommended	Not recommended	0.15	0.064

* 210-degree arc of contact on snubbed head pulley drives and 420 degrees on tandem or dual motor drives are most common.

The trend is toward the greater use of snubbed head pulley drives with 240-degree arc of contact especially on long slope conveyors where a high T_2 exists from belt slope tension.

VALUE OF L. The center length of a conveyor L is measured along the belt between terminal pulleys. The quantity L_c is the corrected length and should be used in horsepower formulas. As already noted,

$$L_c = L + (115 - 0.45L).$$

When belt length is 255 feet or less, the correction factor $(115 - 0.45L)$ will be a positive number to be added to L. For greater lengths, the factor will be negative and therefore subtracted. The horsepower formulas show that the power required to operate a 3,000-foot belt conveyor is less

TABLE 13. BELT CAPACITY

Width of belt, in.	Wt. per cu ft of material, lb	Capacity, short tons (2,000 lb) per hr. Belt speed, fpm: 50	100	150	200	250	300	350	400	450	500	550	600	Cross section of load, sq ft
	35	5	10	15	20	25	30							
	50	7	14	21	29	36	43							
12	75	11	21	32	43	54	64	....	....	.. ..	..	.	...	0.095
	100	14	29	43	57	72	86							
	125	18	36	54	72	90	107							
	150	22	43	65	80	108	129							
	35	12	24	36	48	60	72	83	95					
	50	17	34	51	68	85	102	119	136					
18	75	26	51	77	102	128	153	179	204	.....		. .		0.227
	100	34	68	102	136	170	204	238	272					
	125	43	85	128	170	212	255	298	340					
	150	51	102	153	204	255	306	357	408					
	35	22	44	66	88	110	131	153	175	197	219			
	50	31	63	94	125	156	187	219	250	281	312			
24	75	47	94	141	187	234	281	328	375	422	468	.	. .	0.417
	100	63	125	188	250	312	375	438	500	563	625			
	125	78	156	234	312	390	468	546	624	702	780			
	150	94	188	281	375	468	562	656	750	843	936			
	35	35	70	105	140	175	210	245	280	315	350			
	50	50	100	150	200	250	300	350	400	450	500			
30	75	75	150	225	300	375	450	525	600	675	750	.....	....	0.667
	100	100	200	300	400	500	600	700	800	900	1,000			
	125	125	250	375	500	625	750	875	1,000	1,125	1,250			
	150	150	300	450	600	750	900	1,050	1,200	1,350	1,500			
	35	51	102	152	203	254	304	355	406	457	508	558	609	
	50	73	145	218	290	362	435	507	580	652	725	797	870	
36	75	109	217	326	434	542	651	760	868	976	1,085	1,195	1,300	0.967
	100	145	290	435	580	725	870	1,015	1,160	1,305	1,450	1,595	1,740	
	125	181	362	543	724	905	1,085	1,270	1,450	1,630	1,810	1,990	2,170	
	150	218	435	653	870	1,090	1,310	1,520	1,740	1,960	2,180	2,390	2,644	
	35	71	142	213	284	355	426	497	568	639	710	780	852	
	50	102	203	304	406	508	609	710	812	913	1,016	1,120	1,220	
42	75	152	304	456	608	760	912	1,065	1,218	1,370	1,520	1,670	1,825	1.353
	100	203	406	609	812	1,015	1,218	1,420	1,625	1,825	2,030	2,230	2,440	
	125	254	508	761	1,015	1,270	1,525	1,780	2,030	2,280	2,540	2,790	3,040	
	150	304	609	915	1,220	1,520	1,830	2,130	2,440	2,740	3,040	3,350	3,650	
	35	96	193	289	385	481	577	673	770	865	963	1,060	1,115	
	50	138	275	413	550	688	825	963	1,100	1,240	1,375	1,510	1,650	
48	75	206	413	620	825	1,030	1,240	1,445	1,650	1,860	2,060	2,270	2,480	
	100	275	550	825	1,100	1,375	1,650	1,925	2,200	2,480	2,750	3,020	3,300	1.833
	125	344	688	1,030	1,375	1,720	2,060	2,410	2,750	3,100	3,440	3,780	4,130	
	150	413	825	1,240	1,650	2,060	2,480	2,890	3,300	3,710	4,125	4,540	4,950	
	35	125	250	375	500	625	750	875	1,000	1,125	1,250	1,375	1,500	
	50	179	358	537	716	895	1,075	1,250	1,430	1,610	1,790	1,970	2,150	
54	75	268	536	805	1,070	1,340	1,610	1,875	2,140	2,410	2,680	2,950	3,220	2.383
	100	358	715	1,072	1,430	1,790	2,140	2,500	2,860	3,229	3,580	3,930	4,290	
	125	447	894	1,340	1,790	2,240	2,680	3,130	3,580	4,020	4,470	4,910	5,360	
	150	536	1,072	1,610	2,140	2,680	3,220	3,760	4,290	4,830	5,360	5,900	6,440	
	35	157	315	473	630	788	945	1,100	1,260	1,420	1,575	1,730	1,890	
	50	225	450	675	900	1,125	1,350	1,575	1,800	2,020	2,250	2,480	2,700	
60	75	337	675	1,010	1,350	1,690	2,020	2,360	2,700	3,040	3,370	3,710	4,050	3.000
	100	450	900	1,350	1,800	2,250	2,700	3,150	3,600	4,050	4,500	4,950	5,400	
	125	562	1,125	1,690	2,250	2,810	3,370	3,940	4,500	5,060	5,620	6,180	6,750	
	150	675	1,350	2,020	2,700	3,380	4,050	4,720	5,400	6,070	6,750	7,420	8,100	

TABLE 14. CONVEYOR LENGTH

Actual conveyor length, between centers, ft L	*Corrected length, ft* L_c	*Actual conveyor length, between centers, ft* L	*Corrected length, ft* L_c
50	142	1,100	720
100	170	1,200	775
150	197	1,300	830
200	225	1,400	885
250	252	1,500	940
300	280	1,600	995
350	307	1,700	1,050
400	334	1,800	1,105
450	362	1,900	1,160
500	390	2,000	1,215
550	417	2,100	1,270
600	445	2,200	1,325
650	472	2,300	1,380
700	500	2,400	1,435
750	527	2,500	1,490
800	555	2,600	1,545
850	582	2,700	1,600
900	610	2,800	1,655
950	637	2,900	1,710
1,000	665	3,000	1,765

TABLE 15. CONVEYOR LIFT

Multiply the number in "Lift" column by the length in feet of the inclined part of the conveyor, measured along the belt, to find the vertical distance between head and tail pulley centers.

Incline, deg	*Lift, ft*	*Incline, deg*	*Lift, ft*	*Incline, deg*	*Lift, ft*
1	0.017	9	0.156	17	0.292
2	0.035	10	0.174	18	0.309
3	0.052	11	0.191	19	0.326
4	0.070	12	0.208	20	0.342
5	0.087	13	0.225	21	0.358
6	0.105	14	0.242	22	0.375
7	0.122	15	0.259	23	0.391
8	0.139	16	0.276	24	0.407

TABLE 16. WEIGHT OF MATERIAL PER CUBIC FOOT

Material	*Lb/ft³*	*Material*	*Lb/ft³*	*Lb/bu*
Ore, heavy	150	Slag, granulated	53	65
Ore, average	125	Earth, wet	90	111
Crushed stone	100	Coke	30	37
Sand and gravel, wet	100	Wood chips	20	25
Sand and gravel, dry	90	Wood pulp, damp	30	37
Cement	90	Water	62	76
Cement clinker	95	Wheat	48	60
Earth, dry	70	Barley	38	48
Clay	63	Shelled corn	45	56
Crushed coal	50	Flour	56	70
Ashes, damp	43	Oats	26	32
Salt	45	Rye	45	56

than twice that needed for a 1,500-foot system—indicating one of the advantages of great center distances.

CORD CONVEYOR BELTING

Cord conveyor belts, in which the skeleton is composed almost wholly of longitudinal cords, plus some fabric plies and a transverse cord breaker ply, may be compared with fabric belts as follows:

Impact: Superior to fabric when belt travels more than 500 feet per minute, carries heavy lumps, and rides on idlers 3½ to 4 feet apart.

Tearing, cutting, gouging: Resists these actions better than fabric belts.

Troughing action under high working stress: Superior to stepped-ply fabric belts, especially where operation is over crowned pulleys.

Excessive abrasion: Data are not conclusive, but indications are that softer cord belt will give better wear where abrasion is severe.

Acid resistance: Better than fabric belts because small pinholes admit acid only to a few cords and no blistering results.

FABRIC PLY EQUIVALENT OF CORD BELTS. Some cord belts have a distinct ply construction, while in others the cords are so large that a laminated structure is not achieved. In belt calculations, each cord ply is given the same value as a fabric ply. Thus, in a B. F. Goodrich cord conveyor belt, the ply count to be used in calculations would be the number of cord plies plus the number of 42-ounce duck fabric plies in the belt. (The fabric plies give the belt lateral stability.)

FABRIC VERSUS CORD. In a fabric belt ply, the warp threads (running lengthwise of the belt) are not perfectly straight but zigzag over the filler threads, each bend forming a 45-degree angle. Stress applied to the

kinked warp threads tends to straighten them. It has been calculated that when the kink angle is 45 degrees, in 42-ounce duck an initial stress applied to the belting is increased by about 40 per cent in the fabric. For example, a tension of 45 pounds per inch of width on the fabric would increase actually to 63 pounds per inch of width in the threads of the fabric. The same stress applied to a cord belt remains the same in the individual threads of the cords.

Splicing Conveyor Belting

Fasteners. Steel fastening devices are widely used, even though a vulcanized splice is superior. For small and medium belts, hooks with

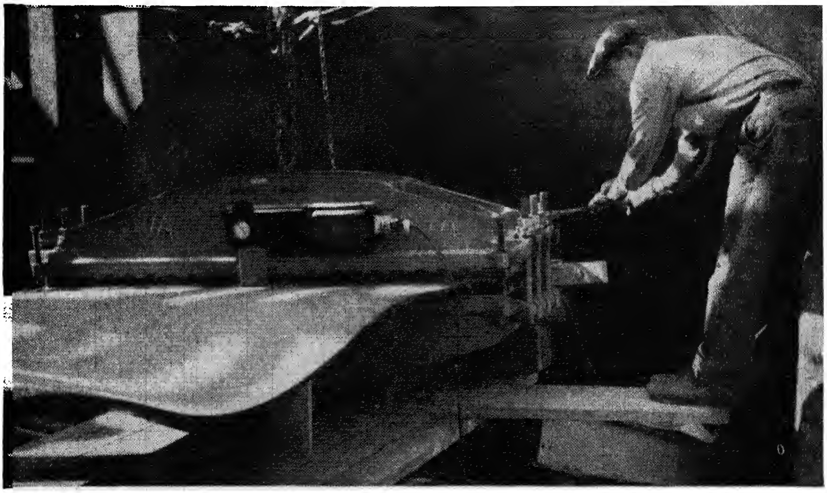


Fig. 4. Splicing an 8-ply, 54-inch-wide, 850-feet-long conveyor belt with a 60-inch diagonal vulcanizer to make it endless.

staggered prongs are suitable. Prongs should clinch longitudinal strands of belt carcass and are driven in from the top of the belt. Points of prongs are turned down with aid of a buck bar held against them, the fastener backs being struck with a hammer.

For heavy belts, fasteners such as the Flexco high-duty type may be used, and such fasteners are sometimes satisfactory on lighter belts. A heavy, unyielding fastener will give trouble when pulley diameters are small. Follow fastener maker's recommendations about pulley size and belt thickness.

Vulcanized Splices. The vulcanized-in-the-field splice is considered one of the greatest improvements in conveyor-belt practice. It is twice

as strong as any metal-fastener type, eliminates much of the accident hazard created by fasteners, is quieter and free from pounding action when passing idlers and pulleys, offers no break in belt cover through which moisture can enter and cause rotting, makes operation in acid possible, prevents burning of fabric by hot materials, resists abrasion as well as the rest of the belt, cannot rust and discolor material being handled, and is not subject to breaking from localized blows.

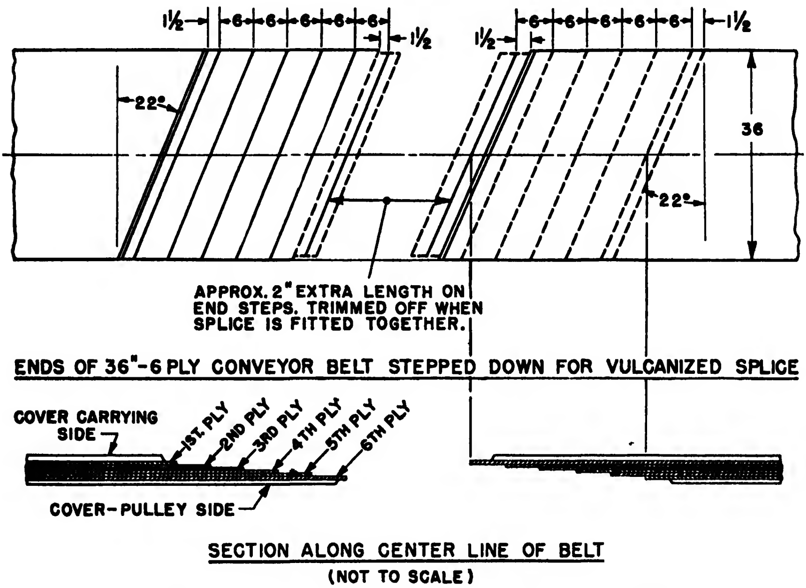


FIG. 5. Ends of a 6-ply conveyor belt stepped down and ready for assembly into a vulcanized splice.

When the carrier permits a 3 per cent take-up, vulcanized splices can be made when the belt is installed. When the take-up is less, it is customary to join the belt temporarily with metal fasteners and run it until part of the stretch has been worked out. Then the metal fasteners are removed and a vulcanized splice made.

MAKING A VULCANIZED SPLICE. Tools needed include yellow crayon; chalk line; carpenter's square; claw pincers with sharp edges of jaws filed off and handles taped; round-end rubber knife; one-ply knife for fabric; screw driver with tip $\frac{5}{16}$ to $\frac{7}{16}$ inch wide and all sharp corners and edges filed off, for use as a ply-loosener; dusting and cement brushes; 2-inch, 4-inch, and sharp-edge roller; coarse abrasive cloth; wire-bristled card-type brush; tire talc or soapstone; awl; belt clamps; guide strips of

iron for confining belt edges in vulcanizer; soft wood blocking strips $\frac{1}{32}$ inch thicker than belt to keep guide strips in place.

Table 17. Guide Strip Thickness

Belt Thickness, In.	*Strip Thickness, In.*
Up to $\frac{1}{2}$	$\frac{1}{32}$ less than belt thickness
$\frac{1}{2}$–$\frac{3}{4}$	$\frac{1}{16}$ less
Over $\frac{3}{4}$	$\frac{1}{8}$ less

Materials include (1) solvent such as a special safety solvent, or one of the following: carbon tetrachloride 100 per cent, a 50-50 mixture of carbon tetrachloride and dry-cleaning fluid, dry-cleaning fluid alone; (2) suitable rubber cements such as B. F. Goodrich Nos. 76 and 77; (3) rubber tie gum on Holland cloth; (4) Grade C uncured rubber cover stock; (5) breaker fabric, such as B. F. Goodrich No. 611 light and No. 609 heavy.

Ends of belt are stepped down by cutting through the carcass one ply at a time and stripping off the plies with the claw pliers. The drawing shows dimensions and arrangement of cuts in splicing a six-ply belt. Take all measurements from a center line drawn along the belt, not from edges. Belt ends should fit together with no evidence of humping or shrinking.

Additional belt length required for a stepped splice on a 22-degree bias is determined for 28-, 32-, 36-, and 42-ounce and No. 50 cord belting by use of the formula

$$L_a = 0.4W + 6(n - 1) + 3 \text{ in.}$$
$$0.4W = \text{length of a 22-deg bias, measured along belt edge}$$

where W = width of belt, in inches
n = number of plies
L_a = additional belt length, in inches

The 3-inch trim results from adding $1\frac{1}{2}$ inches on each belt end stepped down.

For other types of textile cord belting, the formulas are

No. 70 cord:

$$L_a = 0.4W + 8.5(n - 1) + 3 \text{ in.}$$

No. 100 cord:

$$L_a = 0.4W + 12(n - 1) + 3 \text{ in.}$$

Steel-cord belting:

$$L_a = 0.4W + 40 \text{ in.}$$

If there is a breaker fabric ply under the entire top cover, make a 1-inch step in it. This requires removal, at each end, of a 4-inch "trim width" of rubber on top surface, instead of 3 inches when no breaker is used.

Remove the cover stock on the opposite side of the belt to the degree shown in the drawing before stripping down all the plies.

When the belt is fitted together, plies should form perfect butted joints.

Buff the fabric with a coarse abrasive cloth or wire brush, and dust off loose fibers. Apply one coat of rubber cement to fabric steps, and let dry about 15 minutes. Apply a second cement coat, and let dry. Direct sunlight should not strike the cement.

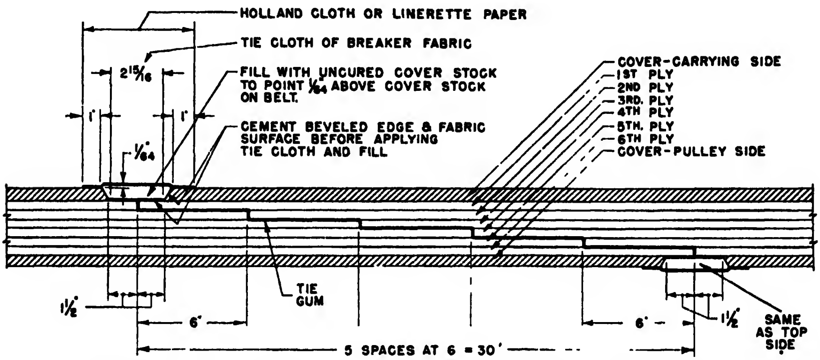


FIG. 6. Section through center line of a rubber-fabric belt before the splice is vulcanized.

Apply sheeted tie gum, with Holland cloth still in place, over steps at one end of the belt, so it extends ½ inch beyond the fabric and over rubber edge stock.

Remove Holland cloth from gum, place bottom ply steps together and roll them into contact, curving the rest of the belt end back out of the way. Then roll second ply steps together, etc.

Clean, roughen, and apply cement to edges of the rubber cover and exposed fabric between. Apply a strip of breaker fabric 1 inch wide centered over the seam. Then fill the balance of the opening with unvulcanized cover stock until it extends 1/64 inch above the belt surface. Roll all rubber layers together, and puncture any air bubbles with an awl.

Apply Holland cloth over the cover fill-in strip, allowing a 1-inch margin on each side. Dust vulcanizing press platens with soapstone or talc.

Guide irons are installed to exert pressure against belt edges during cure. Sometimes hardwood strips wrapped with a layer of Holland cloth are placed between iron and belt to prevent too rapid draining away of heat.

Crude-rubber vulcanizing time for J. C. Heintz 2-platen Vulcanizers is given below.

Belt thickness 3/16 in. and less	25 min
Each additional 1/16-in. thickness	Add 1 min

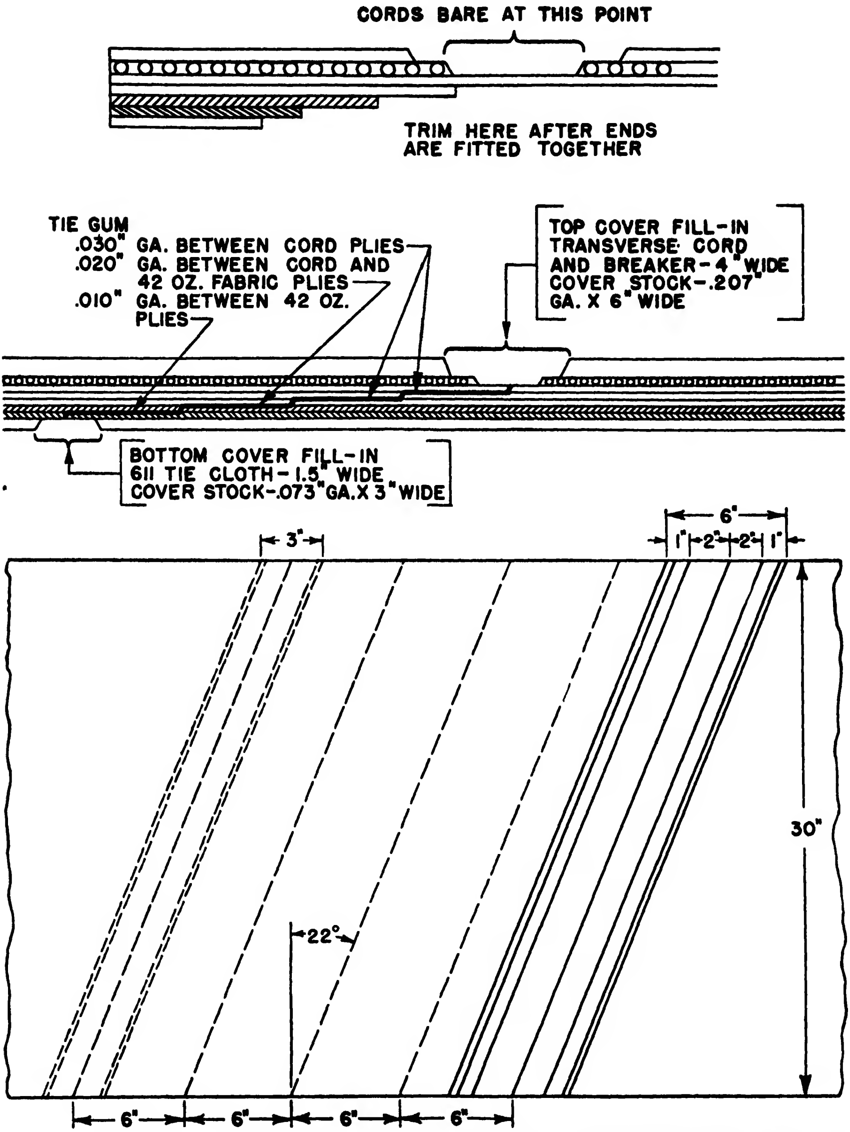


FIG. 7. Details of a typical cord conveyor-belt splice. Dimensions shown are for a heavy-duty belt.

Splicing cord conveyor belts differs but slightly from fabric. The drawing on page 171 shows details.

Belt Break-in

Besides stretching appreciably during a period immediately following installation, a new conveyor belt has to have time to take a "set" so it will conform to the contours of the carriers and run straight. When first installed, it is likely to run crooked because it does not make good contact with the middle idler pulleys. The breaking-in period can be shortened by permitting the fully loaded belt to stand overnight for several consecutive times. The first night, the belt is loaded one-third of its length; the second night, two-thirds; and the third night for its entire length. Perfect alignment of belt with carriers and perfect distribution of load are essential if this method is used.

Flat Belt Repairs

Cuts, gouges, snags, chafed spots, and tears permit moisture to enter and cause rotting of the cord or fabric skeleton of a conveyor or other flat belt.

Temporary Repairs. While awaiting equipment for making permanent vulcanized repairs, temporary repairing can be done as follows:

Materials: Roll of $\frac{1}{32}$-inch combination repair gum vulcanized on one side but not on the other, self-vulcanizing rubber cement, small wire brush, knife, and hammer. (The repair gum and cement are the type used for repairing automobile inner tubes.)

1. Remove all loose cover, and trim edges to 45 degrees with a wet knife.
2. Brush out all dirt.
3. Be sure cover and fabric are dry; then apply two coats of cement, letting each dry thoroughly.
4. Cut repair gum slightly larger than area to be patched, remove protective cloth, and apply tacky side to cemented spot.
5. Hammer patch down evenly, using light blows.
6. Trim all projecting edges of patch flush with cover surface. Patch surface may be below belt surface, but no part should project above.
7. Hammer edges of patch again.

Vulcanized Repairs. Materials and tools required include an electric splicing or belt-repair vulcanizer, wire brush, coarse abrasive cloth, pincers, knife with half-round point, 2-inch hand roller, 1-inch cement brush, some Grade A vulcanizing cement, and unvulcanized sheet cover stock.

Making Minor Cover Repairs

1. Remove cover rubber where loose or snagged, cutting edges at a 60-degree angle, letting knife blade penetrate all but about $\frac{1}{64}$ inch of cover. Tear out unwanted rubber, exposing fabric.
2. With wire brush and benzine or other solvent when necessary, clean fabric. Roughen fabric and edges of rubber cover with abrasive cloth. Be sure fabric is dry.
3. Apply coat of cement, and let it dry 30 minutes; apply a second coat, and let it dry. Do not do this in direct sunlight or in rain.
4. Apply layers of Grade C unvulcanized cover stock, rolling each into contact and deflating air bubbles with awl, until cavity is filled level with rest of cover. Save the Holland cloth or linerette paper that protected rubber surfaces.
5. Cut piece of Holland cloth or linerette paper $\frac{1}{2}$ inch larger than patch, and lay it over unvulcanized rubber.
6. Clamp vulcanizer over repaired area, and cure patch at a heat of 287°F. Pressure should be moderately heavy and evenly applied. Time required for curing patch:

Cover thicknesses up to $\frac{1}{8}$ in.	25 min
Each additional $\frac{1}{16}$ in.	4 min

When wood or belting-stock insulating pad is not used beneath belt, add 15 minutes to above times.

Note: If unvulcanized rubber stock loses its tackiness, wash it with high-test gasoline or carbon tetrachloride or apply a coat of Grade A rubber cement.

Making Major Cover and Carcass Repairs

So great is the variety of such repairs that only general suggestions can be made.

When injury to the fabric carcass is slight, loose or torn fabric can be removed and the cavity filled with cover repair stock.

When damage is greater and the fabric must be replaced in two or more plies, each ply is cut out $1\frac{1}{2}$ to 3 inches larger all around than the one immediately below. Best practice is to make longitudinal cuts parallel to the belt edges and cross cuts at an angle of approximately 68 degrees to the belt edges.

Cut the unvulcanized repair fabric so the warp threads run lengthwise of the belt, the filler threads crosswise, and make the pieces rather large so the fabric has to be crowded into the cavity.

Cut the rubber cover back $\frac{3}{8}$ inch from edges of the cut in the top ply.

Roughen the fabric in the cavity, apply two coats of cement and let each dry, and then fill the cavity to the level of the top ply by rolling in successive layers of ply-repair material of the same weight as that used in the belt. If there are skim coats of rubber between the plies, install similar skim-coat repair stock or use repair fabric having a skim coat attached to one surface.

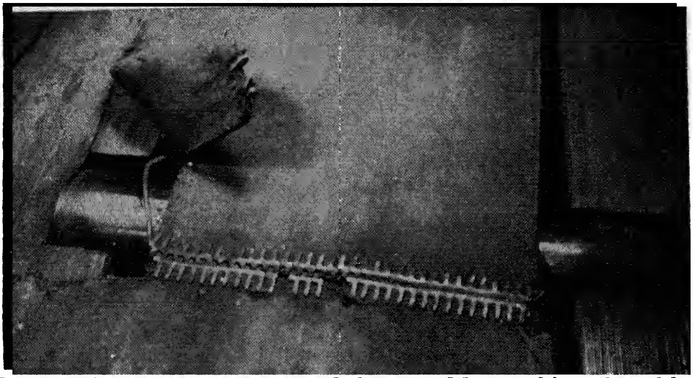


FIG. 8. Longitudinal tear in a conveyor belt, caused by catching of steel lacing pin on an obstruction against which the belt rubbed.

After the fabric has been restored, fill the cavity to $\frac{1}{64}$ inch above the belt surface with unvulcanized cover stock or, when several plies have been restored, to $\frac{1}{32}$ inch. Vulcanize in the manner already described.

TABLE 18. CURING TIMES FOR REPAIRS INVOLVING BELT CARCASS

Single-platen vulcanizer:	
Temperature	287°F.
Thickness of unvulcanized *repair stock* to $\frac{1}{8}$ in	25 min
Each additional $\frac{1}{16}$ in	4 min
Limit of repair depth	$\frac{5}{16}$ in.
Double-platen vulcanizer:	
Thickness of *belt* up to $\frac{3}{16}$ in	25 min
Each additional $\frac{1}{16}$ in. of *belt* thickness	1 min

(A single platen vulcanizer applies heat to one side of belt only; double platen, to both sides.)

If repair involves more than one-third of belt width, it is advisable to cut a section from the belt and splice in a new piece.

For long, longitudinal slits through conveyor belt, cut cover and two plies from each surface, using stepped method, and install new plies and rubber after cleaning cut and filling it with cement.

For repairs at edge of belt, use a triangular stepped arrangement with base of isosceles triangle along belt edge.

Loading Equipment

Loading Technique. Material to be moved by a conveyor belt is guided to the belt surface by chutes. Good design requires that the chutes be shaped and placed so belt damage and wear are at a minimum.

Material should leave the chute moving in the same direction as the belt and at a speed as close as possible to the belt speed.

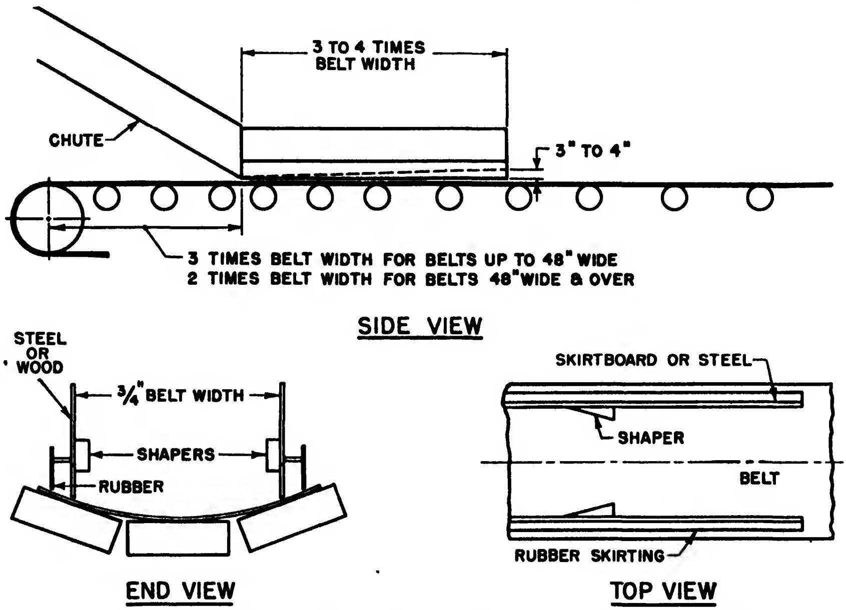


Fig. 9. Conveyor-belt skirt boards used on 48-inch conveyor carrying coal. Lower edge of each board is 6 inches in from belt edge (1/8 belt width), and edge clearance increases in direction away from loading point. Soft-rubber skirting (lower left) reduces spillage through tapered opening between boards and belt. Shapers guide lumps toward belt center.

Feed should be arranged so that fine material falls on belt first to provide a cushion for coarser material. A simple way of accomplishing this is to cut a rounded or V-shaped notch in the bottom of the chute.

If chute is steep or discharges 3 feet or so above the belt, baffles made of iron bars or iron sheets should be arranged to slow the fall of large chunks.

Do not locate the chute where the material will strike the belt directly over a pulley if it can be avoided. When the loading point must be directly over a pulley, the pulley should be of the pneumatic impact type (made like a series of small automobile tires) or mounted on rubber

shock-absorbing units. Another way is to remove the central idler pulley at that point.

No stationary part of the chute should touch the belt, and there should be ample clearance to prevent wedging of material between chute and belt.

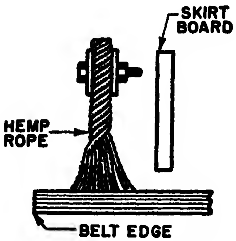


Fig. 10. A secondary skirt board made by clamping short pieces of hemp rope between metal strips prevents fine material from falling off a conveyor belt. (*Courtesy of E. Leet, The Beech Bottom Power Co.*)

Chatter, which sometimes causes wedging, can be eliminated by locating the lip of the chute a distance from the tail pulley equal to three or more belt widths and installing troughing idlers between the chute and tail pulley to steady the belt.

Idlers should be spaced close together at the loading points in order to reduce vibration. For heavy material, the spacing may be 12 to 18 inches.

When the belt changes direction from horizontal to an incline, curve the carrier gradually to meet the incline.

Skirt Boards. Boards used to guide the load for a short distance after it leaves the chute should never touch the belt. Spacing between boards and belt should increase in direction of belt travel in order to prevent wedging of load particles. Bottoms of skirt boards should be fitted with rubber strips, but even these strips will cause wear if they rub against the belt.

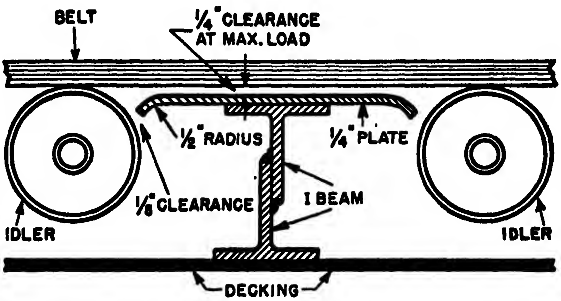


Fig. 11. Decking or shield arranged under top strand of a conveyor belt to prevent the belt from being torn by loose jingle bars that may find their way through the hopper. (*Courtesy of The Ohio Power Company.*)

The length of skirt boards beyond the chute should be 3 or 4 times the belt width. Skirt boards should be used along the entire belt length only when they are needed to prevent spilling.

Fine material may be prevented from spilling beneath the skirt boards

by installing hemp-rope "brooms" as illustrated. This method was suggested by E. Leet, of The Beech Bottom Power Company.

Preventing Lump Damage to Belts. Severe damage can be caused by lumps trapped between belt and pulley or by moist material caked on pulley surfaces. Remedies include (1) brushes, which usually clean satisfactorily for a while but soon wear out; (2) scrapers made from strips of old belting (they often cause rapid belt wear), steel scraper bars, which remove caked material from snub or tripper pulley (they wear rapidly, need inspecting often); (3) installation of decking over return side of the belt. This is the best method. Decking should be kept clean to prevent the material from accumulating and interfering with the idlers. (4) In some conveyors, decking has to be placed just under the top length of the belting to prevent tearing of the belt by loose bars that come through the hopper. A typical decking system is illustrated, by courtesy of C. B. Watson of the Ohio Power Company.

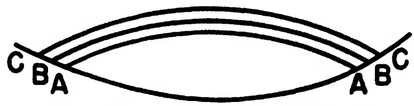


Fig. 12. Cross section of conveyor load showing how reduced speed saves a 24-inch belt. At 500 feet per minute, load size to transport 140 tons of crushed material an hour is indicated by line *A-A*; at 400 feet per minute, *B-B*; and at 300 feet per minute, *C-C*. Load *C-C* passes loading chute 3/5 as often as *A-A* in discharging same volume of material, and belt wear is 40 per cent less.

Belt Speed and Wear. Tonnage moved by a conveyor can be kept at a maximum by loading the belt to full capacity. This often permits the belt speed to be lowered, thus decreasing wear on all parts of the system. The sketch shows various loadings necessary for a 24-inch belt at different speeds, in order to carry 140 tons of crushed coal per hour. Speed required for various load sizes is

Load	*Ft/Min*
AA	500
BB	400
CC	300

Loaded fully (*CC*), the belt passes the loading chute only 60 per cent as fast or often as when partly loaded at *AA*, and belt wear is decreased 40 per cent.

Conveyor Belt Mountings

In designing a conveyor, engineers attempt to place idler carriers just close enough together to support the belt and its load without prohibitive sagging. If there is excessive sag, the load is constantly shifting and belt wear is rapid.

Conveyor operators have lowered costs by using a graduated idler spacing. They separate the idlers in proportion to belt tension. This tension, on the carrying side, is a maximum at the head pulley and decreases to a minimum at the tail pulley. Therefore the spacing at the head pulley is greater, say 4 feet. This decreases gradually to perhaps only 2 feet at the tail pulley. Exact spacing depends on the conveyor

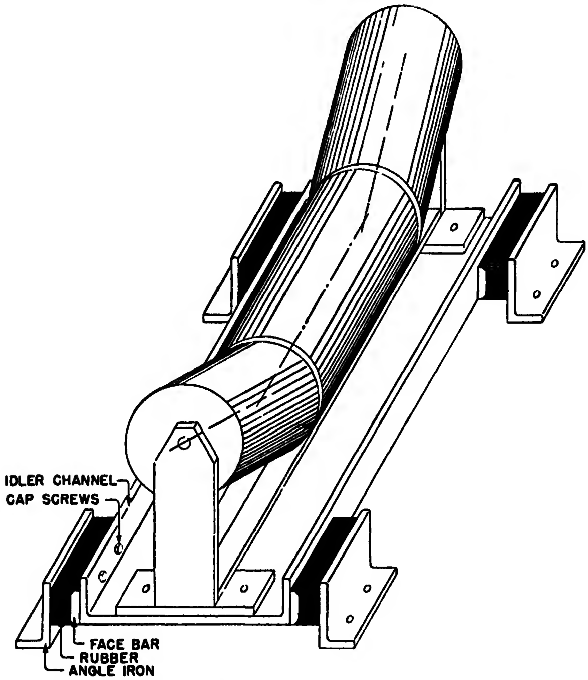


Fig. 13. Conveyor-belt idlers arranged to make belt form a trough. The assembly is mounted on rubber suspension units that protect belt from loading shocks. (See Fig. 14.)

inclination, belt width, load, and belt tension, and it can be found most easily by trial-and-error adjustments and power readings at different settings. Use the setting that requires least power to operate the conveyor.

Idler carriers usually have three or more cylindrical pulleys mounted so that the center one is horizontal and the end ones slope upward. This arrangement causes the belt to trough properly, and a troughed belt can carry a greater load than a flat one. Idlers on the newer conveyors have antifriction bearings.

Shock Impact Mountings. Most belt wear occurs at loading points as a result of impact of material being loaded. When loading conditions are ideal, belt wear may not be excessive, but an ideal loading arrange-

ment is a rarity. Shock impact mountings for idlers provide an effective way of reducing loading wear.

Methods of absorbing conveyor belt impact include the following:

1. Rubber-covered idler pulleys directly below the feed point. The impact has to travel through the conveyor belt in order to reach the idler covering, and in doing so it is largely absorbed by the belt structure. The thicker the idler covering the more effective it is as a shock absorber.

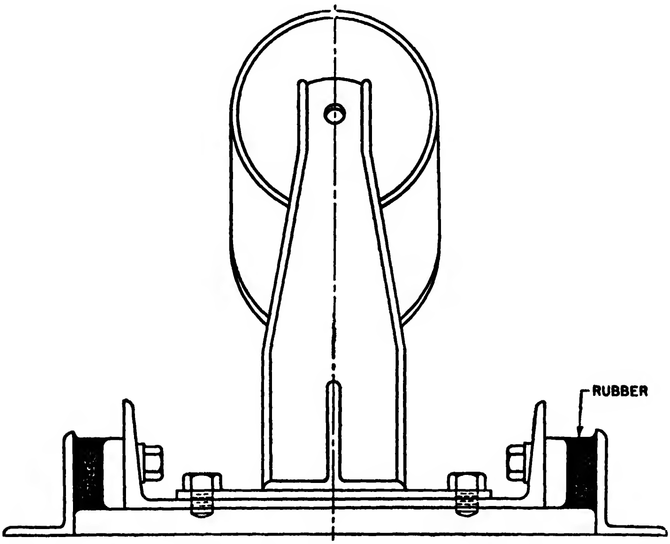


FIG. 14. Conveyor-belt idler on rubber impact mountings. The rubber permits the idler to give slightly when subjected to loading shocks, thus protecting belt cover from abrasion, cutting, and gouging. Length of each rubber suspension unit is selected to match load requirements. (See Fig. 13 preceding; also Chap. 10.)

2. Idlers made by placing T-shaped rubber segments on a shaft. This design permits greater use of the rubber, approaching the effect obtained with a pneumatic tire.

3. Idlers made by assembling small pneumatic tires on a shaft, their surfaces forming a ridged pulley surface. Satisfactory, but quite costly.

4. Idlers mounted on a frame or bed supported by metal springs. Satisfactory, but usually costly.

5. Idlers mounted on a frame or bed supported by rubber shock-absorbing units. Shock impact mountings consist of a steel face bar and angle iron strip between which a block of rubber is vulcanized. Mounted as shown, the rubber is in shear, and therefore it distorts more easily and absorbs impacts more readily than rubber in compression. The belt,

idler, and idler frame recoil under the impact of heavy chunks or other shock. Normally, four rubber shock-absorbing units are used for each idler frame. Idlers are adjusted to the impact normally encountered, by varying the lengths of the rubber mountings. For 48- to 60-inch belts, mountings 4 inches long will handle light impact, 6 inches usually will handle fairly severe conditions, and 8 inches, very severe impact. For belt widths less than 48 inches, mountings are correspondingly shorter.

Crooked-running Conveyor Belts

Making a conveyor belt run straight can become a serious problem. Some ways of doing it follow.

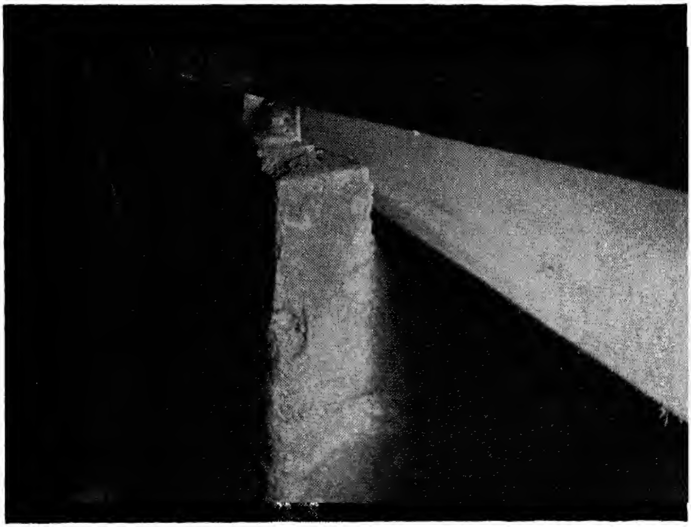


Fig. 15. Belt being damaged by crooked running which causes edge on return side to rub against a concrete abutment.

1. Straighten the belt itself. A crooked belt is indicated when the same part of the belt tends to run off, no matter where it is on the conveyor. Causes of crookedness include (*a*) ends not square at splice. When splicing, mark a center line 15 feet or so back from each end, and square the end with it—not with the belt edges, which may not be straight. (*b*) Belt edge worn off. If belt tension is high, worn edge will stretch. If belt becomes wet, worn edge may shrink as result of shrinkage of fabric.

2. Check alignment of idlers. Misalignment is indicated when belt tends to climb sidewise on same idlers. Usually the idler that is out of

line is the second or third one behind the point where the belt goes astray. Adjust idlers so they are 90 degrees with center line of belt.

3. Check second flat idler behind tail pulley on return side. Sometimes adjusting this will cure crooked running.

4. Inspect idlers to see if any are loose. If a return idler slides to one end of shaft, it will throw belt out of line.

5. If conveyor is on temporary foundation, misalignment of supports may be cause of crooked running.

6. Tilting idler carriers slightly forward will usually improve operation. This can be done by placing shims under rear foot of the support on each side. Outer tips of end-pulleys, journals, or shafts should move forward $\frac{1}{8}$ to $\frac{3}{16}$ inch, no more. Use of a template is advisable. On reversing conveyors, idlers must be perpendicular, not tilted either way.

7. Installing a self-aligning idler or two on return section of belt will help center it over tail pulley. Place one such idler just ahead of tail pulley, the second 50 to 75 feet ahead.

8. Loading belt more equally may cure crooked running. In unequal loading, the heavy side seeks middle of carrier, forcing other edge to climb. Realignment of chute usually is first step in securing even loading.

9. Inspect idlers to see if any are frozen. A jammed pulley tends to deflect belt.

10. When belt does not make good contact with horizontal middle pulleys of idlers, it will not run straight. Belts having too many plies in proportion to their widths sometimes develop this trouble. Increasing belt load may be the remedy. This can be done by delivering more material or by slowing down belt so load per foot will increase at previous input delivery rate.

11. One conveyor operator saved more than $1,000 a year by installing "jingle bars" to control the load. These are heavy steel bars suspended from a horizontal support above the chute in such position that their lower ends strike the load. By arranging the bars properly according to their weight, an uneven load can be persuaded to drop evenly on the belt. Besides slowing down the velocity of the material, the bars act to alter direction of the particles.

Safety Cutoff for Hoppers

When a hopper that feeds a belt becomes clogged and overflows, the spilling material may damage the conveyor. To prevent this, a swinging baffle can be arranged near the top of the hopper so that when piling material presses against it, an electrical switch will be opened, stopping the conveyor.

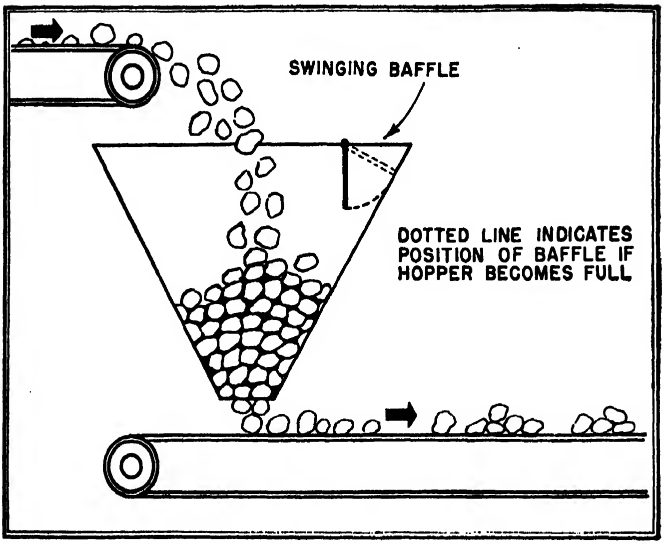


FIG. 16. Safety device for conveyor-belt hopper. When the hopper becomes clogged, it fills and pressure of the load causes the swinging baffle to move to right and open an electric switch that stops the conveyor. The switch may control a relay that in turn disconnects the motor power supply. (*Courtesy of Rock Products.*)

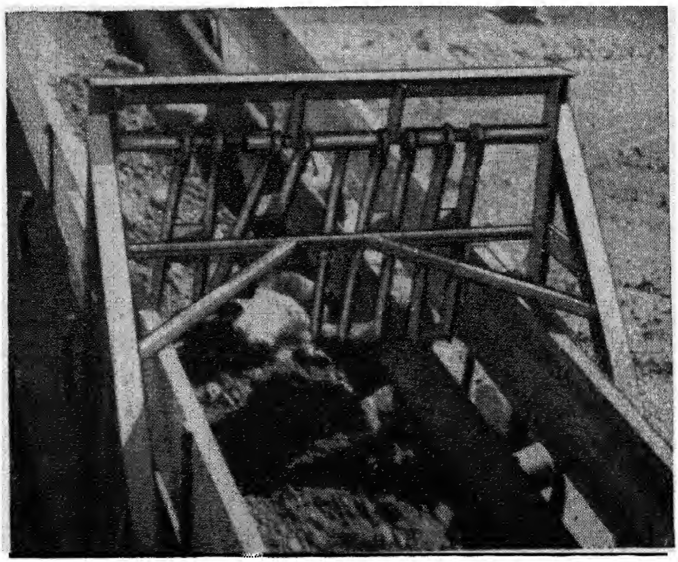


FIG. 17. Swinging steel bars arranged to prevent rollback of lumps on an inclined conveyor. Bars placed at intervals along the belt swing freely in the direction of belt travel but cannot swing backward beyond their normal at-rest position.

Inclined Conveyor Safety

Material being carried up a steeply inclined conveyor may roll backward, creating a hazard to workmen and equipment. Two measures should be taken to prevent this. (1) Install wide side boards along the belt edge, to prevent spilling. (2) Place antirollback devices at intervals along the incline. These consist of a series of suspended steel bars resting against a horizontal brace that prevents them from swinging backward. Lower ends of the bar clear part of the load but not large lumps. The bars swing forward to permit the load to pass; but because they cannot swing backward, they catch disloged chunks and cause them to start up the conveyor again.

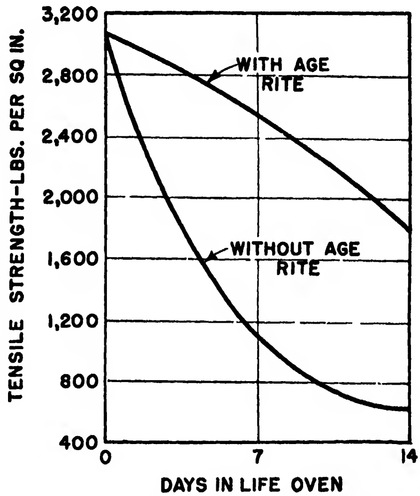


Fig. 18. Conveyor belts give long service because of extended laboratory research on the materials that go into them. The curves show results of accelerated-aging tests on two samples of belt-cover compounds, one of which contained an age resistor (AgeRite). Two weeks in the "life oven" are equivalent to about seven years of normal aging.

Protective Conveyor Belt Coating

When conveyor installations stand idle for long periods, the rubber belt, if unprotected, may deteriorate considerably. This aging usually shows up as short, numerous cracks in the belt cover when the belting is bent sharply. Protective coatings have been developed for brushing on idle belts to prevent surface checking.

Identifying Belting Rubber

Before transmission or conveyor belting can be repaired successfully, the kind of rubber used for the belting and splicing material must be known. When identifying marks have become obliterated, the following simple tests can be used:

Repair Gum. Immerse uncured repair material in gasoline. If it immediately becomes soft and smeary on the surface and rubs off on the fingers, it is either crude rubber or GR-S rubber. If it does not soften, it is a Neoprene type American rubber.

Adhesive. Cement for crude rubber or GR-S consists of a black and a gray part and has a gasoline odor. Cement for Neoprene-type American rubber is a single-part black cement and has an acetate odor.

Vulcanized Belting. Clean an area of the belt surface. Heat a piece of clean copper wire, such as stripped No. 14 household electric wire, in a blue or "colorless" flame until it begins to redden. Touch the heated wire against the belt surface. In the same flame reheat the wire that touched the rubber, and note the color of the flame. If it is green, the rubber is a Neoprene type. Otherwise the material is crude rubber or GR-S. This test can be used for identifying Neoprene products other than belting.

Chapter 8

FLAT RUBBER BELTING—ELEVATOR

While a belt conveyor is designed for transmitting material horizontally or along moderate inclines, a belt elevator, which operates vertically or nearly so, is used for lifting material from one level to another. Essentially, an elevator belt is a strip of conveyor-type belting to which buckets or angle strips are bolted at intervals.

Belt elevators may be classified into two groups:

1. Spaced bucket or scoop feed elevator
   a. Buckets separated a considerable distance from each other
   b. Belt operates at speed that causes buckets to be discharged by centrifugal force
   c. Buckets are generally loaded by digging into material
2. Continuous-bucket elevators
   a. Buckets placed close to each other
   b. Belt operates satisfactorily at "flat" inclines and at slow speeds, and each bucket pours its load out over the inverted adjacent bucket
   c. Buckets are generally loaded from a chute, by "fly feeding"

Elevator-belt Construction. Belting used in elevators has more plies than conveyor belting of the same width in order to provide greater lifting strength. Duck weight ranges upward from 32 ounces. Because elevator belts usually take a lot of punishment, the design should allow a wide margin of safety with respect to belt strength and quality. When belt wear on the pulley side is rapid, operators sometimes attempt to prevent it by using belts having more fabric plies. It is better to increase the thickness of the rubber cover on the pulley side instead.

Feeding Elevator Belt. Precautions should be taken to prevent material from spilling between the boot (bottom) pulley and the belt. When a fly feed is used, where the material is directed on the belt by a chute or spout, there should be at least two empty buckets below point of impact to catch spilled material. Most belt elevator accidents are caused by material between boot pulley and belt.

Boot-pulley Design. To minimize the danger of accidents or damage to belt, boot pulleys are often made so that trapped material will be rendered more or less harmless. Squirrel-cage and wing-type boot pulleys have been used considerably. The Sprout-Waldron wing-type

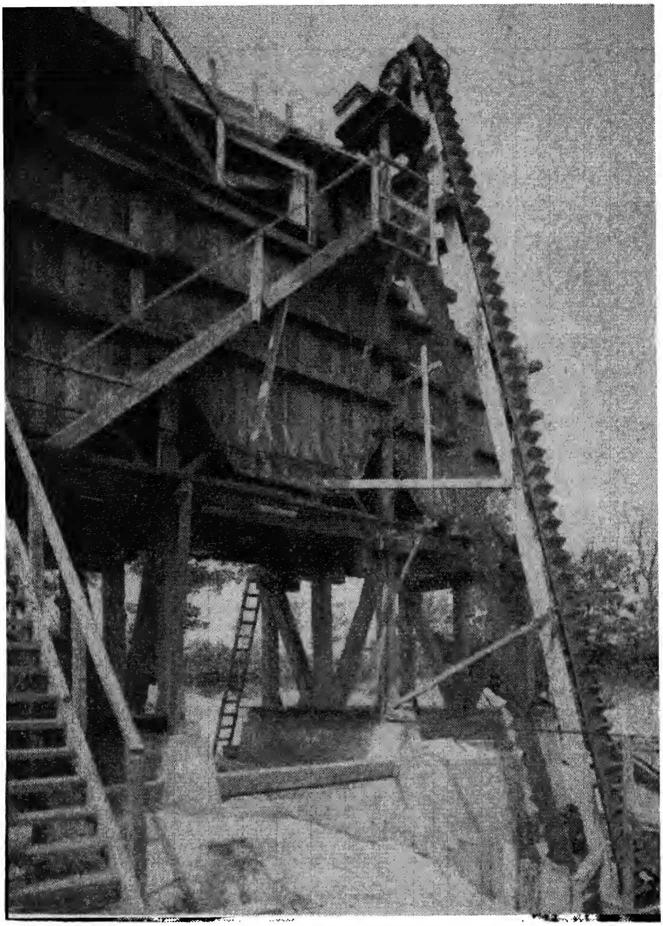


Fig. 1. An elevator belt carrying material up a steep incline. Buckets are open at the front.

pulley looks somewhat like a river-steamer paddle wheel. Lumps that fall into the pulley slots cause no harm, but those wedged between the belt and face of pulley bars may cause trouble.

A boot pulley is sometimes protected by a deflector made of sheet iron or of wood covered with old belting and shaped like an inverted V. This "roof" is placed directly above the pulley, between the belt strands.

Unless inspected and adjusted frequently, such a deflector may prove more harmful than helpful.

Elevator Pulleys. Faces of head (top) and boot pulleys should be 2 inches wider than the width of the belt.

Faces of the pulleys, particularly the boot, should be thicker than those of similar sized pulleys used for power transmission.

Boot pulley of a large belt elevator may be smaller than the head pulley, usually between 75 and 80 per cent of its diameter. Pulleys are usually of the same size in small elevators.

The diameter of the head pulley should be sufficient to prevent abnormal distortion of the belt. This is related to the ply number of the belting. Table 1 shows preferred maximum pulley diameters for various belt thicknesses:

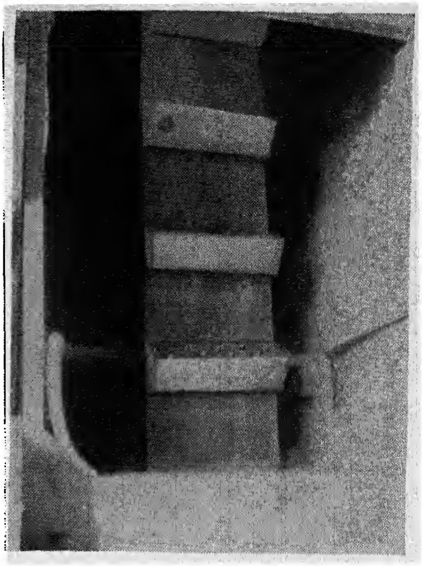


Fig. 2. Buckets on this vertical elevator belt are closed at the front and are shaped somewhat like bread pans.

Table 1. Maximum Plies of Elevator Belts

Diam. of Head Pulley, In.	*No. of Plies*
24	5
30	6
36	7
42	8
48	9
54	10
60	12
72	14

Belt Speed. The speed of a spaced-bucket elevator belt must be sufficient to cause the load to leave the buckets properly by centrifugal force. This is dependent upon head-pulley diameter, as shown in Table 2.

Increasing Pulley Grip. Head-pulley slipping, resulting in loss of power and damage to belt, may be retarded or stopped by (1) applying rubber lagging to pulley face, (2) using a pulley with a vulcanized rubber cover (see rubber-covered rolls), (3) using a canvas lagging where operating conditions keep pulley too wet for rubber, (4) using a slotted cast

TABLE 2. ELEVATOR BELT SPEED FOR CLEAN CENTRIFUGAL DISCHARGE
Such as grain elevators operating at high speeds

Head pulley, rpm	*Head pulley diam., in.*	*Belt speed, fpm*
52.5	24	330
46	30	360
41	36	390
38.5	42	425
36.5	48	460
34.5	54	490
33	60	520
31	66	540
30	72	570
28	84	610
26	96	650
25	108	700
23	120	730

iron pulley with face left unmachined, the slots running diagonally across face.

APPLYING RUBBER PULLEY LAGGING. Lagging stock is made in various widths, thicknesses of 1/32, 1/16, and 1/8 inch, and in two-, three-, and four-ply construction.

Clean the pulley to remove old glue and dirt.

Cut the lagging so it passes once around the pulley and meets in a butt joint. Use a steel square when cutting.

Apply fish glue or shellac to the surface of the pulley. Press the lagging into place, and pound butted ends down tightly.

At a distance of 1½ inches from each end, install a row of ¼-inch elevator bolts having large, flat heads. Place additional bolts in staggered rows around circumference of pulley, between arms or spokes. Before applying adhesive or lagging, drill bolt holes and countersink them to receive the bolt heads.

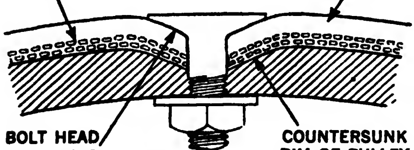


FIG. 3. Section through a pulley showing how rubber lagging is bolted in place. Such a lagged pulley may improve the performance of a conveyor or an elevator belt.

Slippage under wet conditions can be reduced by herringbone grooving of rubber lagging. Grooves are easily cut with a hand tire-grooving tool before lagging is applied. Lagging is in two pieces, one for each half of pulley, and should be thick enough to take ¼-inch-deep grooves. Cut

grooves ¼ inch wide, with ¼-inch ridges between. The angle of the grooves with respect to the edge of lagging is about 70 degrees (20 degrees with the pulley axis or squared ends of pieces). Grooves in one half run in one direction, those in the second half in another, forming a herringbone pattern when they meet in the pulley center. Grooved lagging is fastened to the pulley in same way as ungrooved.

When surfaces are not extremely wet, rubber lagging increases the coefficient of friction between the belt and pulley about 20 per cent. Use of old belts for lagging does not prove so satisfactory as use of lagging stock made specially for the purpose. Lagging should be renewed from time to time to prevent the bolt heads from projecting and injuring the belt. Lagging also may be attached by the Vulcalock process.

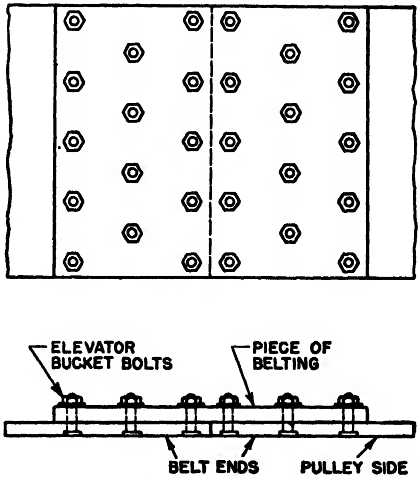


FIG. 4. Method of making a butt splice on an elevator belt.

Rubber lagging is equally effective on conveyor pulleys.

BUCKETS. Elevator buckets are listed by manufacturers according to their actual volumetric size. Carrying capacities relative to this volume are

Actual or struck volume	*Fine material (grain, sand, etc.)*	*Coarse material (crushed rock, etc.)*
100%	Up to 90%	Up to 75%

FASTENING BUCKETS. Punch bolt holes with a sharp, hollow belt punch after the holes have been laid out with aid of a square and a template—or the bucket itself used as a template. Install the bolts with their heads on the pulley side of the belt, and place the rounded faces of the nuts next to the bucket. Lock washers beneath the nuts will retard loosening.

SPLICING ELEVATOR BELTS. Kinds of splices used include (1) lap joint, where the belt ends are lapped a distance equal to the belt width and fastened with elevator bolts. Buckets may be attached by the same bolts. (2) Butt joints, where a square piece of belting is centered

over the joint and secured with standard elevator or Jackson bolts. For belts up to 10 ply, use ½-inch bolts; for thicker belts, use ⅝-inch bolts. (3) Butt joint, which uses plate and button fasteners of Flexco or Jackson type.

Elevator-belt Tension

Maximum tension (T_{max}) occurs where the belt is about to pass over the head pulley.

$$T_{max} = A + B + C + D + E$$

where A = weight of one-half of belt. For light belts with thin covers, weight per foot, in pounds = width (inches) × number of plies × 0.035
For heavy belts with thick covers, weight = width (inches) × number of plies × 0.05
B = one-half of total empty bucket weight
C = maximum weight of material being carried upward. Find weight of material carried in each bucket, and multiply this by number of buckets on rising side
D = Friction in boot and bearings
E = the initial tension of belt

For a scoop feed elevator, D is equivalent to the weight, in pounds, of the material carried by 25 to 50 feet of belt. When the material carried is fine, the resistance is less and the material on 25 feet of belt would be about right. Resistance increases in proportion to boot-pulley diameter. For a chute feed, reduce D by one-half. When the maximum horsepower rating of the elevator is known,

$$C + D = \frac{\text{hp} \times 33{,}000}{\text{fpm}}$$

where hp = horsepower of drive
fpm = belt speed in feet per minute

Unless $C + D$ is considerably larger than $A + B$, initial tension can be ignored. Also, lagging of head pulley may eliminate the necessity of considering initial tension. Usually the belt and bucket weight on the descending side is sufficient to prevent slipping toward the loaded side. When initial tension is included in computation, it generally is 2 to 5 pounds per inch of belt width per ply.

Number of Plies Required. When the maximum tension is known, the number of fabric plies required in an elevator belt can be determined by using the formula

$$T_{max} = WNT_p$$

or

$$N = \frac{T_{max}}{WT_p}$$

where W = width of belt in inches

N = number of fabric plies

T_p = maximum tension per ply per inch width

Table 3 shows the values of T_p normally encountered:

TABLE 3

Weight of Duck, Oz	T_p, *Lb*
28	24
32	28
36	30
42	45

ELEVATOR-BELT LENGTH. Length of belt required, in feet, can be calculated as follows:

$$L = 0.131\ (D + d) + 2C$$

where D = diameter of head pulley in inches

d = diameter of boot pulley in inches

C = distance between centers of pulleys in feet

CARRYING CAPACITY. Carrying capacity of an elevator belt can be calculated as follows:

$$C = \frac{0.36 \times SWB}{D}$$

where C = capacity of elevator in tons per hour

S = belt speed in feet per minute

W = weight of 1 cubic foot of material carried in pounds

B = volume of one bucket in cubic feet, or cubic inches/1,728

D = distance between buckets in inches

This formula gives the capacity if buckets were "solidly" loaded. In actual practice, buckets never carry their full volumetric capacity, so the value found for C must be multiplied by the fraction that represents the degree of bucket capacity utilized. Thus, when grain is being loaded with buckets filled to 90 per cent of their actual volume, the tonnage would be 90 per cent of that calculated.

To find the capacity in bushels of wheat per hour (1 bushel of wheat weighs 60 pounds), multiply C by 33.33.

Chapter 9

EXTRUDED RUBBER

If you ever pressed toothpaste from a collapsible tube, you have performed one of the oldest and most useful processes involved in rubber manufacture—extruding. Pressure applied to the plastic material (toothpaste) forced it through a die (tube mouth) in the form of a continuous ribbon of definite shape, technically called the extrusion.

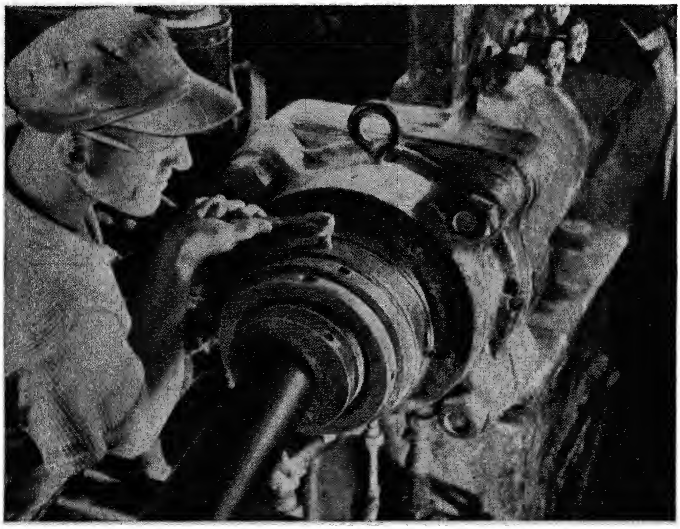


FIG. 1. Extruding a rubber tube. The extruding machine, often called a tube machine, resembles a giant food grinder or sausage stuffer.

In practice, the machines used for extruding crude and American rubber and plastics are similar to another everyday article, the food or sausage grinder. A rotating screw forces the compound through a die having one or more openings shaped to produce the cross section desired. When the material is a thermoplastic, the cylinder of the extruding machine is heated by hot water, steam, hot oil, or electricity. As the extruded plastic issues from the die, it is chilled by running it into a tank of water or by some similar method—and the job is done. But in

the case of a rubber compound, which is thermosetting but not thermoplastic, the extrusion is considerably short of being finished as it issues from the die, for it has to be vulcanized.

Extruding Dies

These are steel plates, usually circular in shape, having openings through which the compound is forced by pressure. Dies are made of

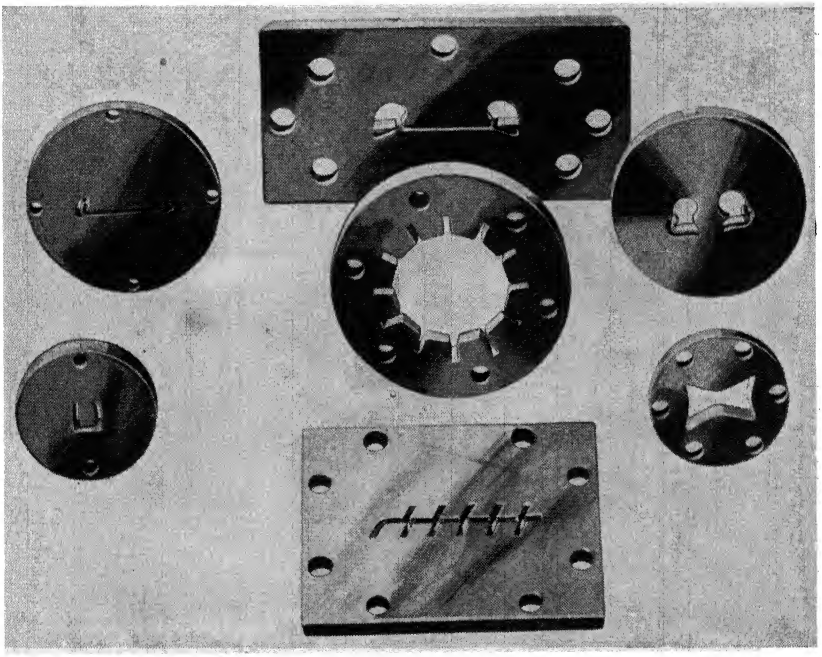


Fig. 2. Extruding dies are made of high-grade steel plate.

high-grade, sometimes of hardenable, steel and generally range from ¼ to 1 inch in thickness. Production dies may be test-run before being hardened; and if the shape and size of the orifices are not exactly right, corrections can be made easily by filing. A die may be of one-piece construction, the opening being cut in a solid disk, or it may be made by assembling two or more sections.

Die Openings. There are no set formulas for determining the sizes and shapes of extruding die openings. Many of the factors governing the final dimensions and shapes required to produce an extrusion are variable. And so the job of making a die is largely a matter of trial and error based on considerable experience and knowledge of rubber and

plastic compounds. Dies are almost always designed and made by the manufacturer who will do the extruding.

In designing a die, allowance must be made for swell of the extruded rubber as it issues from the machine and for shrinkage that occurs during curing. Soft compounds exhibit greater swell than hard. The amount of swell and shrinkage varies with the compound. The extruding machine and the way it is run have an effect on swell, as does also the rate at

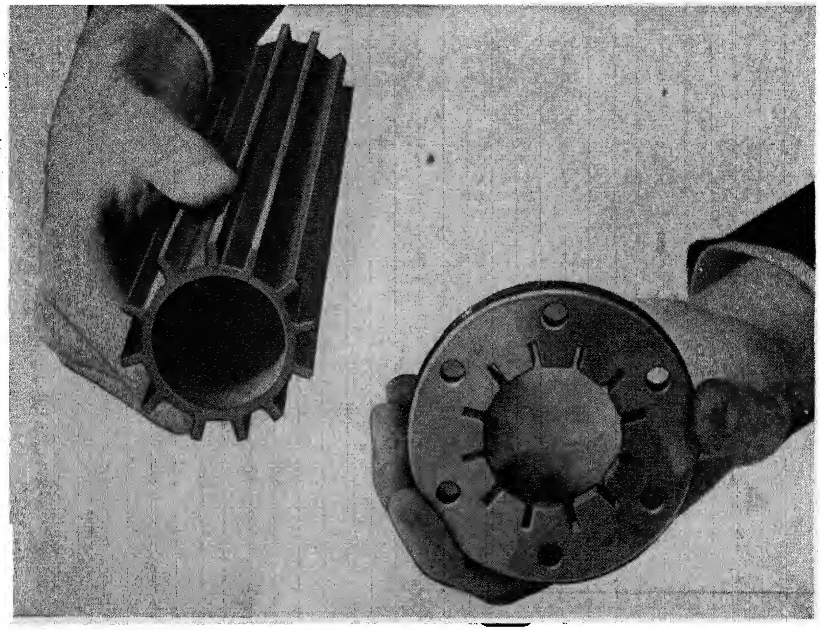


FIG. 3. A steel extruding die, right, and the rubber part it produced.

which the extruded part is moved away from the die. A die to be used for extruding thermoplastic material generally has an opening varying from about the same size as the finished extrusion to perhaps one-fourth larger. Because of the effect of swell, shrinkage, take-off belt speed, and other factors on the final profile dimensions of an extrusion, it is absolutely necessary that the die designer has a good knowledge of the compound and the manufacturing equipment to be used, before he can turn out a die that will produce anywhere near the shape and size desired. And he can do a better job if he is consulted when the design for the rest of the assembly in which the extrusion will be used is still in the preliminary stages of development.

Experience and tests guide the diemaker in determining the amount

the die openings should be enlarged on the entrance (machine) side and in placing flow channels in order to prevent excessive drag and produce a uniform extrusion. Length of the opening measured back from the exit surface also influences drag.

SHAPE OF OPENING. The shape of the aperture in an extrusion die is seldom the same as the shape of the part extruded. Thus a die that produces a strip of square or rectangular cross section may have an opening that has curved sides and looks like a pincushion. Here, again, experience and trial are the best guides.

POLISHING. Dies are carefully polished, which makes possible a smooth finish on the product. Plastic-extruding dies are sometimes chromium-plated.

INTERCHANGEABILITY. Usually, extruding dies are not interchangeable between factories or even between machines, and a die made for a particular American-rubber compound cannot be used for shaping another kind of American-rubber, crude-rubber, or plastic material. A die that produces the desired shape with crude or American rubber of a certain durometer hardness will not work with the same material of a different hardness. Even the pitch of the extruding machine screw has a definite effect on the extrusion.

DIE COST. The cost of typical extruding dies in the shops of one rubber manufacturer averages from $8 for the simpler forms to around $30 for more complicated ones; and for an extremely difficult extrusion, the cost may reach $75. Plastic-extruding die costs have been reported as high as several hundred dollars. It is a practice for the customer to pay the cost of a rubber-extruding die.

TOLERANCES. For extrusions whose height and width are not more than 2 inches, the tolerance is $\pm 1/32$ inch.

For extrusions over 2 inches, the tolerance is $\pm 3/64$ to $1/16$ inch.

When dimensions are critical with the customer, a manufacturer will attempt to meet the customer's tolerances.

COMPOUNDS

Rubber compounds intended for shaping by extruding are essentially the same as those to be processed by molding or other methods. They contain whatever pigments, age resistors, accelerators, and other ingredients the product requires. Some extrusions, such as refrigerator gaskets, require stocks that are tasteless, odorless, and of suitable color. The compound may have to be resistant to various oils or definite chemicals. Compounds are milled to mix the ingredients thoroughly and are batch-tested before going to the extruding machine.

American-rubber, crude-rubber, and plastic compounds intended for extrusion are not essentially different except to the extent that they affect die shape and size. Extruded thermoplastic materials may be compared with crude and American rubbers as follows:

The ideal durometer hardness for plastics is 80. Lowest easily extruded hardness is around 40.

Maximum durometer hardness for easy extrusion of rubber compounds is around 85; the minimum, 45 $\pm$ 5.

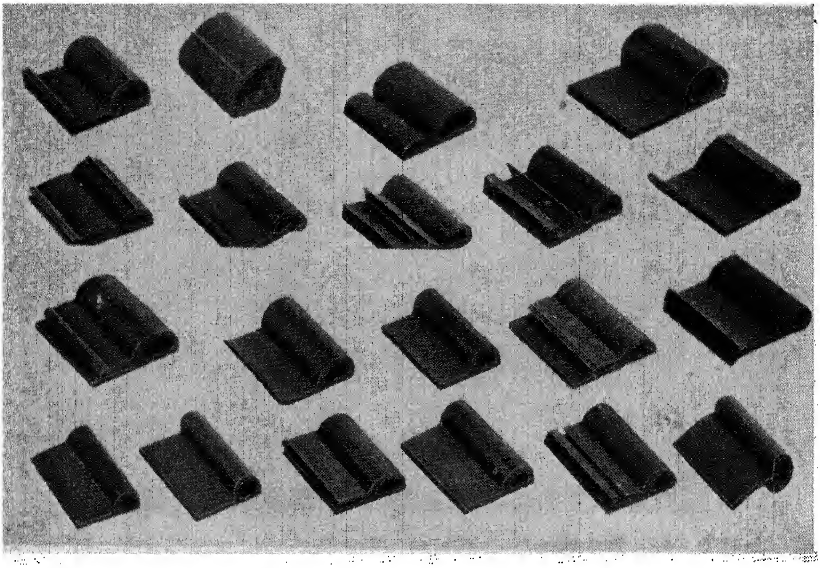


Fig. 4. These sections of rubber show only a few of the conventional shapes easily produced by the extrusion process.

Below a hardness of 45, rubber extrusions must be supported on forms until vulcanized.

Plastics have a "deader" feeling than rubber extrusions.

In large sizes, plastic extrusions are not so flexible as those made of rubber. In smaller sizes, plastics compare favorably with rubber.

Plastics have better tensile strength than reclaimed rubber extrusions. They are about equal to natural crude rubber in this property.

Plastics are easier to extrude in thin sections than rubber.

Forms of Extrusions

Conventional and easiest to make extruded shapes are round, square, rectangular, and hollow round (tubing).

COMBINATIONS. Often part of an extruded strip must remain flexible and part must be rigid. Refrigerator gaskets and aircraft parts frequently have these qualities.

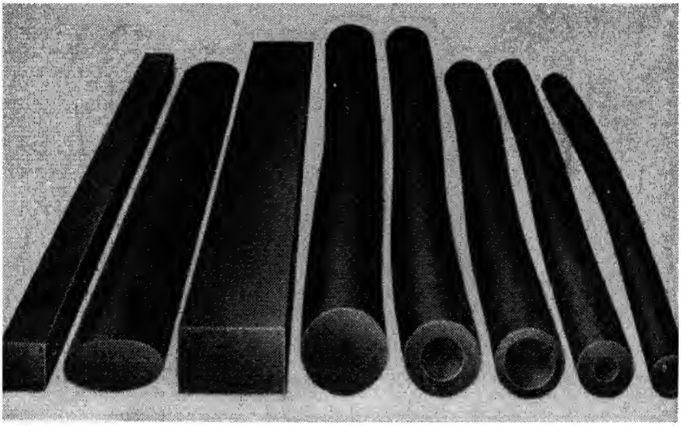


FIG. 5. Rubber or plastic tubing and cord can be made in countless sizes and shapes by the extrusion method.

Masonite Strip. One combination consists of a strip of Masonite embedded in the rubber extrusion. The strip is fed through the extruding machine, which is designed for the purpose, and the rubber is extruded completely around it. The embedded strip supports the extrusion both during and after curing. It prevents stretching, eliminates distortion, provides a secure means of fastening with nails, bolts, or screws.

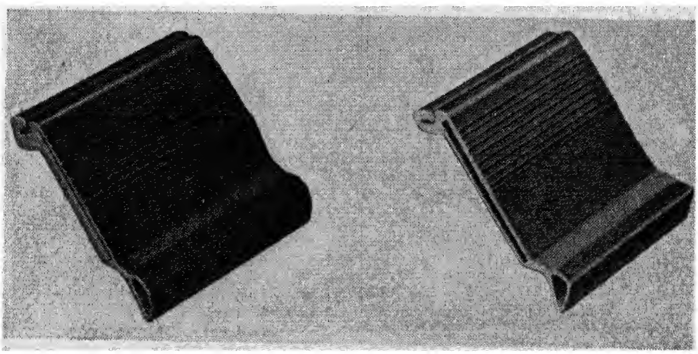


FIG. 6. Rubber is extruded around reinforcement strips to produce products for special installations where rigidity is required.

Wire Mesh. The rubber compound may be extruded around wire or wire mesh that provides a secure means of fastening and contributes to the support and limitation of stretch.

Fig. 7. This extruded strip has a wire or wire-mesh insertion that enables it to be attached securely with nails, screws, or other fastening means.

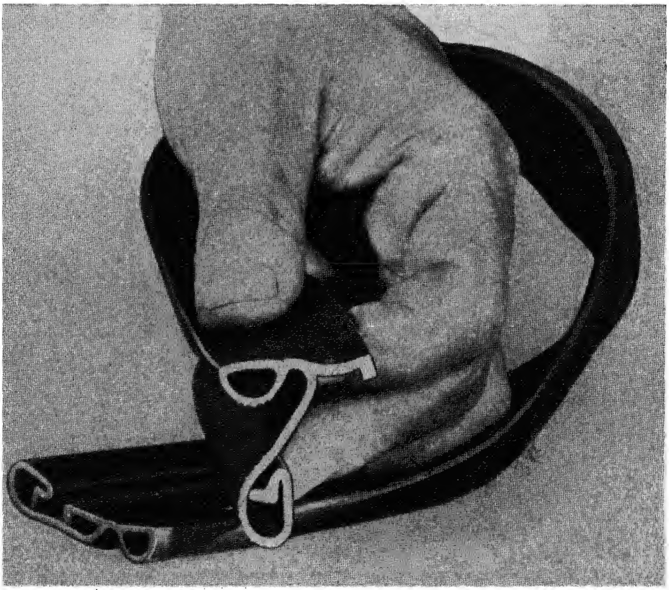


Fig. 8. Extruded rubber-gasket strip having a lip that can be clamped between two metal plates. The means of attachment is always an important design factor in such extruded products as refrigerator gaskets.

Clamping Lip. An extruded gasket often has a lip that is used for fastening. The lip may be clamped between metal members of an assembly or secured beneath a strip of metal or other material that is held in place by bolts or screws.

Hard and Soft Rubber. These two types of compounds may be extruded together. When cured, they are firmly united; yet one part of the extrusion is hard, the other soft. Thus in a gasket strip, the hard rubber facilitates fastening and helps reduce stretch or other distortion.

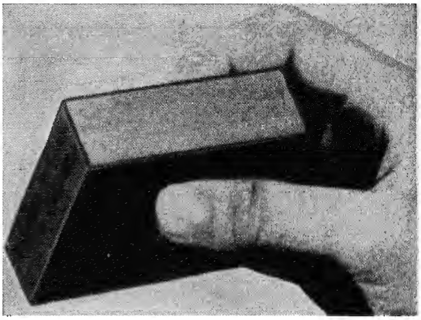


FIG. 9. Sponge rubber around which has been extruded a protective cover of solid rubber.

Sponge Gasket. Smooth, solid rubber is extruded around sponge-rubber cord or strip to form a gasket having high compressibility and low permanent set. A wire or thread running lengthwise prevents stretching while the gasket is being handled and installed.

Cork Insulation. When granulated cork is mixed with the rubber compound and extruded in the form of a tube, the result is an insulating product that is light in weight, flexible, and particularly adapted for installing around pipes and tubes. It is used chiefly for insulating cold lines in refrigeration work.

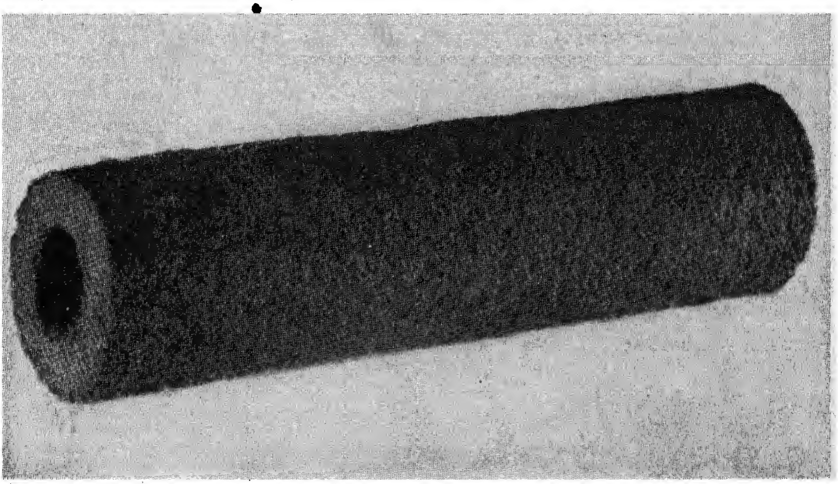


FIG. 10. This flexible, lightweight insulator for cold lines was made by extruding a rubber compound in which bits of cork are suspended.

Intricate Shapes. It is a common saying among the men who make extruded products that no shape having a uniform cross section is too complicated to be produced by extruding. However, these same men have found by experience that there are limitations governing the relative sizes of different portions of an extruded section, the separation between portions such as lips, etc. For instance, if an almost circular or C-shaped section is extruded with only a small separation between the

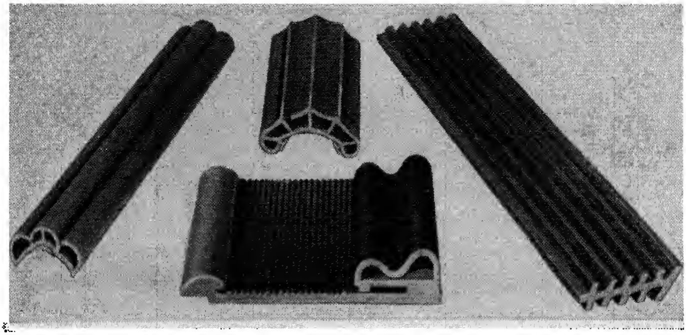


Fig. 11. These complicated shapes of extruded rubber are examples of what a skillful diemaker can do.

edges, it is likely that during vulcanization, the gap will close. Wall thickness must be sufficient to provide support for tubular parts during vulcanization. The design, construction, and operation of die equipment are simplified by keeping uniform the cross-sectional dimensions of the extrusion.

Size Limitations

Size of extruded products is limited by available factory equipment or simply by the fact that no one has asked for anything larger. The following are typical limitations on diameters as applied to vulcanized extruded rubber products:

Shapes	*Inches*
Round or square, min	0.060
Square, max	4 by 4
Rectangular, max	3 by 6

Plastics. Plastics have been extruded in sizes ranging from threads to widths of several feet. For Koroseal compounds, the most practical extrusion diameters are ⅛ to 1½ inches.

TABLE 1. TYPICAL LENGTHS OF EXTRUSIONS

Lengths, rubber (thermosetting material):	*Feet*
Small sections that can be coiled	Average 800 to 1,000
Larger sections	Average 50
Intricate shapes	Generally 12 to 14
Lengths, plastic (thermoplastic materials):	
Plain shapes and tubing	Unlimited, or as determined by shipping reel capacity

Factors governing lengths in which extruded products are manufactured include

1. Length in which the parts are used. Manufacturers incorporating

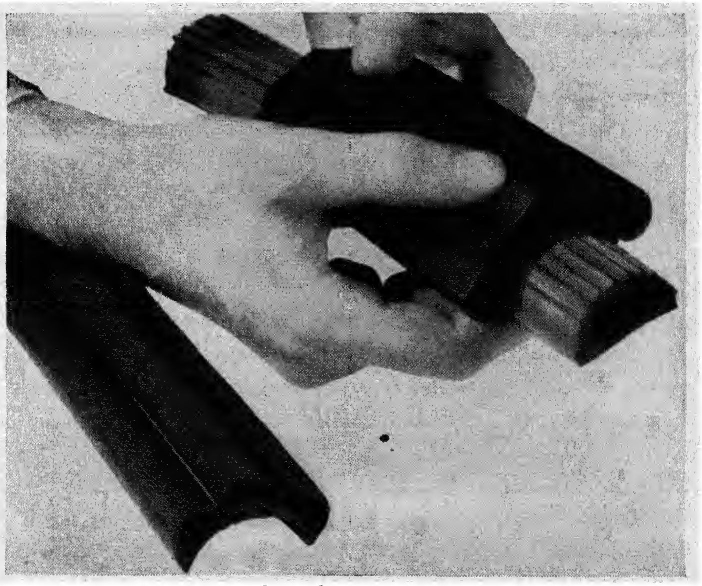


FIG. 12. Some kinds of extruded products must be vulcanized while supported by rigid forms, in order to retain their shape.

extruded units in their products find it economical to have the parts cut to the lengths required by the assemblies.

2. Multiple dies. Such dies, permitting extrusion of several strips simultaneously, may best be used when straight lengths are permissible.

3. Wide, rectangular, and irregular strips. These are generally produced more satisfactorily when vulcanized in straight lengths.

4. Notching, splicing, and other finishing operations generally require definite, predetermined lengths.

5. Round and square sections and those which can be supported during vulcanization on a narrow edge can be coiled. Coiling extrusions from single-hole dies may be less economical than producing shorter straight sections from multiple dies.

Waste

The manufacture of rubber articles by extruding is economical of material because waste can be reduced to a minimum. When an extruded section comes out of the tube machine in an imperfect condition, it is simply remilled with fresh stock and extruded again.

Size of Runs

Extruding is primarily a quantity-production operation. Short runs are not economical. To prepare a tubing machine for production costs a minimum of about $25. This includes the expense of setting up the machine, cost of stock that must be in the machine before any can be extruded, and mixing costs of the stock, which usually is a special compound. The first stock extruded is not generally usable because of included air bubbles and perhaps improper die performance. When the job is finished, there remains in the extruding head a quantity of stock that becomes "head scrap." A No. 2 Royle (2-inch) tube machine holds about 15 pounds of head scrap; a No. 3 Royle (3-inch), 20 pounds. This scrap cannot be used for making products of the same quality but can be employed in the production of lower quality items. Thus a compound costing 40 cents a pound may, after becoming head scrap, be used in a mix worth 10 cents per pound. The smallest amount of compound that a factory will extrude on any one job is usually around 125 pounds, including the scrap. When the quantity of rubber extruded is large, the cost of setup and loss from head scrap become negligible. But on short runs, the setup and scrap costs are no lower and may represent a considerable percentage of the total product cost.

Aftertreatment

Uncured Extrusions. The extruded strip is either coiled or cut into lengths as its size and shape require or permit. Intricate shapes often have to be supported on forms made of metal, hard rubber, or other suitable material so they will not become distorted while being vulcanized. Extrusions generally are cured by open-heat methods. If the product engineer can alter his plans to permit use of an extrusion that does not have to be supported during vulcanization, costs will be less.

Mold Blanks. Stock is often extruded and cut to fixed lengths in order to produce blanks for loading mold cavities. Because the extrusion is uniform, it is easy to regulate the volume of stock by cutting to length. Also, the extruded shape can be made to match closely the shape of the

product, thus helping to attain minimum flow of the material in the mold. It is generally agreed that by keeping flow to a minimum, a better product is produced in a shorter period of time.

CURED EXTRUSIONS. After a gasket strip or other extruded part has been vulcanized, it may receive various kinds of treatment to fit it for its ultimate use. Notches may be cut at intervals, to permit bending or insertion into a machine or other assembly of which the extrusion is to become a part. Holes may be drilled or punched at specific points, so the part can be bolted or otherwise fastened in position. Gasket strips are often spliced, by cementing and vulcanizing, to form endless "picture-frame" seals for refrigerator doors and other units.

NEW PRODUCTS

The design engineer who believes that an extruded part will work into his new-product plans because of its low cost, uniformity, and other desirable features may save himself a lot of useless work and his company considerable money by consulting the technical staffs of rubber manufacturers who produce extruded goods. Extrusion dies are not discarded after completion of the production run for which they were made. They are filed away and kept clean and free of rust, ready for use again if they should be required. Manufacturers have thousands of such dies on file, and the shapes they are capable of producing encompass just about every type that can be imagined—from simple tubes to complicated gaskets.

Often it is possible for an engineer to make slight alterations in his original design to permit him to utilize an extruded shape that already has been produced and whose die is on file. In this way, die cost can be eliminated, and production can begin with a minimum of delay.

The best time for the product designer to get in touch with the technical staff of a rubber manufacturer is at the beginning, when the design is still in the early paper stage and therefore can be changed readily. This is true of all other rubber industrial products, as well as extrusions. Even if the manufacturer has no standard extruded shape that will fill the requirements, he often can suggest changes that will lower costs and make the extrusion do a better job. It sometimes happens that a product engineer will work out plans involving extruded parts and perhaps even may have stamping dies and other production equipment made before he consults experienced extrusion men. The problem then becomes one of developing an extrusion that will work with parts not designed for it—a problem sometimes extremely difficult to solve. By calling in the rubber technicians early in the play, such situations can be avoided.

Chapter 10

RUBBER MOUNTINGS

Excessive vibration in an engine, motor, air compressor, punch press, or other piece of machinery has a multitude of effects. It reduces equipment life, disturbs near-by instruments, and may cause undue muscular tensions, digestive disturbances, and unnecessary expenditure of bodily energy in workmen. Excessive vibration traveling through the earth, a building, or a piece of equipment may disturb photomicrographic cameras, electron microscopes, sound-recording and -reproducing equipment, delicate meters, and other laboratory and electronic apparatus. The elimination or control of such vibrations is an important science in which rubber is playing a leading part. Often a few ounces of rubber will protect a costly piece of machinery from ultimate damage, increase the over-all efficiency of workmen and decrease their errors, and result in a drop in employee abseenteeism.

There are three ways of handling a troublesome vibration in, say, an engine: (1) The crankshaft and other moving part may be balanced to reduce off-center mass. (2) Dynamic vibration absorbers may be attached to the crankshaft or other moving part. (3) The engine may be mounted on elastic supports that confine practically all of the vibrations to the engine itself. While one or all three of these methods may solve a particular vibration or noise problem, this chapter will be limited to a consideration of (3) and to the use of elastic suspensions in which rubber is the cushioning material.

Isolation. The ideal method of confining vibrations to a piece of machinery would be to float it in space where it could oscillate without causing a disturbance in anything else. It is not feasible to suspend a piece of factory machinery or similar mass in space. The next best thing is to mount it on elastic vibration-absorbing units. An alternating force generated within the suspended machine is prevented by the elastic suspension units from traveling to surrounding masses, except for a relatively small force that is transmitted by the suspension itself and is called the spring force.

Frequencies. The natural frequency of a suspended mass is the number of oscillations it makes in a second or other time unit after a single impulse acts upon it. This frequency is influenced by the characteristics of the suspension and the weight of the suspended equipment.

The disturbing frequency imposed on a suspended mass is that generated by revolutions of a flywheel, explosions of gases, or other similar

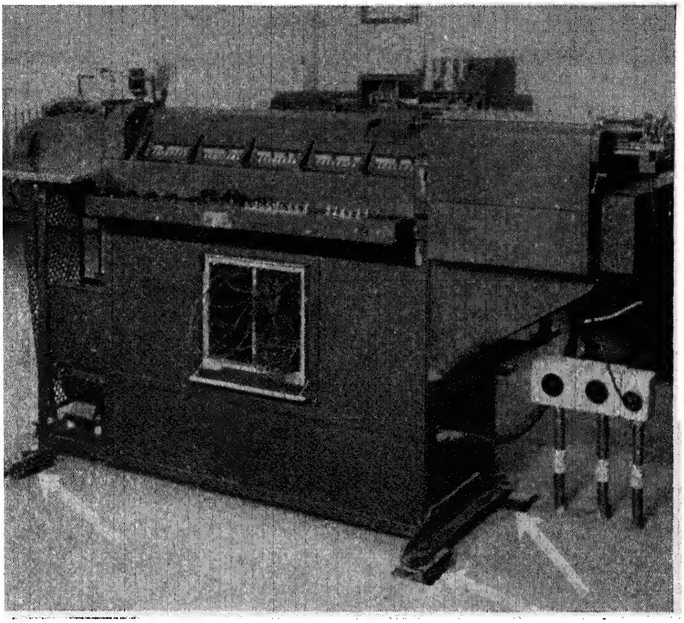


Fig. 1. A business machine mounted on rubber vibration insulators. Rubber mountings of this type are commonly used beneath heavy machinery such as internal-combustion engines to prevent troublesome vibrations from traveling to the foundation, surrounding buildings, and nearby personnel.

actions. Often there are a number of disturbing frequencies involved. In such cases, the lowest one is used in calculating suspensions.

If the natural frequency and the disturbing frequency happen to reinforce each other, a resonant condition exists and the suspended machine will undergo excessive vibration. If there is considerable difference in the two frequencies, the problem of isolating the disturbing frequency is simplified. This difference is usually created by altering the natural frequency.

Theory of Vibration Elimination. The drawing shows a weight W stretching a coil spring a distance D. The weight, when pulled down and released, will oscillate vertically, its movements obeying the laws

for a simple pendulum. Thus the oscillations per second can be calculated using the formula

$$f = \frac{3.13}{\sqrt{D}}$$

where f = oscillations per second = natural frequency of spring when supporting W

D = amount in inches the spring is deflected when weight W is at rest

If the weight W is increased or decreased, or if the stiffness of the spring is altered while the weight remains the same, the deflection D will be correspondingly changed, and consequently the natural frequency of the system will be different. Thus it generally is a simple matter to alter the natural frequency of a machine or other mass supported by elastic suspensions.

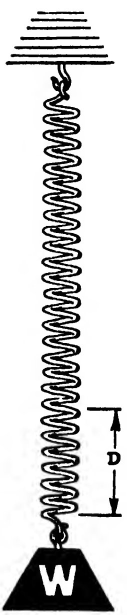


FIG. 2. An oscillating weight suspended by a spring obeys the laws of the pendulum.

Any elastically restrained mass, such as a machine mounted on rubber, obeys the same physical laws as a simple pendulum. This behavior is a function of the mass and its elastic restraint and is equally applicable whether the mass is within the earth's gravitational pull or not.

It was stated a few paragraphs back that a resonant condition exists when natural and impressed frequencies are in step and that good isolation requires that there be a difference in these frequencies. For proper isolation of vibration in a mass suspended on rubber springs, the lowest impressed or disturbing frequency should be no less than 2.5 times the natural frequency of the mass. As the impressed frequency becomes progressively less than 2.5 times the natural frequency, the amount of vibration transmitted by a rubber spring or other flexible suspension increases as compared with the amount a nonspringing support would transmit. When the ratio of $\sqrt{2}$, or 1.4142, is reached, transmitted vibration theoretically equals the initial vibration. Beyond this point, transmitted vibration is greater than impressed vibration, until the resonance point is reached (frequency ratio 1:1) and the vibration transmitted by an undamped suspension becomes "infinite."

If

$$V = \frac{\text{vibration transmitted by a rubber spring}}{\text{vibration transmitted by a solid mount}}$$

and

$$r = \frac{\text{impressed frequency}}{\text{natural frequency}}$$

then

$$V = \frac{1}{r^2 - 1}$$

Thus, when the ratio $r = \sqrt{2}$,

$$V = \frac{1}{(\sqrt{2})^2 - 1} = 1$$

or, when ratio $r = 1$,

$$V = \frac{1}{1^2 - 1} = \frac{1}{0} = \infty$$

RUBBER SPRINGS. Rubber springs (or mountings) are replacing metal springs and other materials in numerous installations. In many instances, they are superior to steel springs because they are easier to install, have greater sound-insulating ability, or impart more lateral stability. Rubber springs can be given greater deflection per unit area than cork or felt; and they have no tendency to crumble under prolonged vibration and heavy loads.

Rubber can be employed in three ways in suspensions: (1) in tension, (2) in compression, (3) in shear.

Rubber in tension is seldom used because of the danger of failure by tearing.

Often rubber in compression is preferred and recommended. One of the chief reasons for preferring compression mountings is that the load-deflection curve for rubber in compression is usually a variable rate having increased stiffness at larger deflections.

When a large deflection is required, rubber suspensions usually are designed to carry the load in shear. This greater deflection results in maximum noise absorption and vibration absorption. Shear springs can also be stressed more highly than other types because the stress is more uniform.

SELECTING RUBBER SPRINGS. Rubber suspension units are designed for carrying specific maximum loads and for handling definite minimum disturbing frequencies. Their characteristics may be modified, when necessary, by varying such properties as the hardness of the rubber compound or size of the unit.

The selecting of a suitable insulator may be outlined as follows:

1. Determine the lowest disturbing frequency generated in the machine or the lowest such frequency that might be transmitted to the

instrument or other mass to be isolated. In a machine, this frequency may be the rpm of a motor, impacts per minute of a hammering action, etc. A suspension selected to isolate the lowest disturbing frequency will be even more effective for higher frequencies.

2. Determine the actual loaded weight of the machine.
3. Determine the portion of the total weight each suspension point supports. When this cannot be done readily, the machine name, model, number, and maker's name should be supplied to the suspension manufacturer.
4. Select the proper suspension from a manufacturer's table. The listed

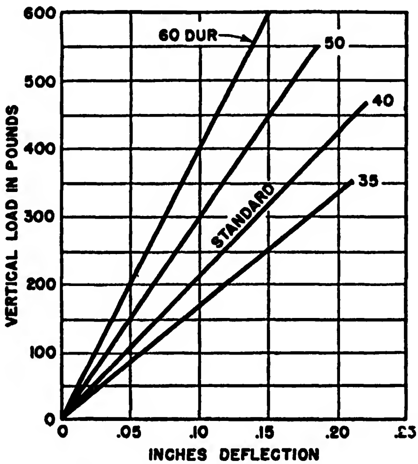


FIG. 3. Typical loading-deflection chart for a rubber vibration insulator. This shows behavior of the larger rubber button of a two-part compression-type mounting designed primarily for isolating internal-combustion engines. See Figs. 4, 17, and 18.

frequency that the mounting will isolate at the specified load should be as low as the lowest disturbing frequency.

MOUNTING. Each rubber suspension unit is designed to bear a definite maximum load per insulator or per unit of its length. If the proper types of insulators are selected and placed so that each bears its share of the total load, a uniform deflection of the insulators can be achieved. Uniformity of load distribution prevents overloading and possible premature failure of some suspension units, prevents sagging and enables the machine to maintain normal horizontal position, and makes possible maximum isolation by fully loading each suspension unit. An underloaded spring in a set will lower the efficiency of all the others.

In a suspended machine, the simplest form of torsional oscillation is that which takes place around the center of gravity or an axis passing through it. For greatest stability and flexibility, it often is preferable to mount all the vibration-absorbing units so they and the center of gravity

are in or nearly in the same plane. As an example, a radio receiver whose center of mass is approximately the dimensional center of the cabinet

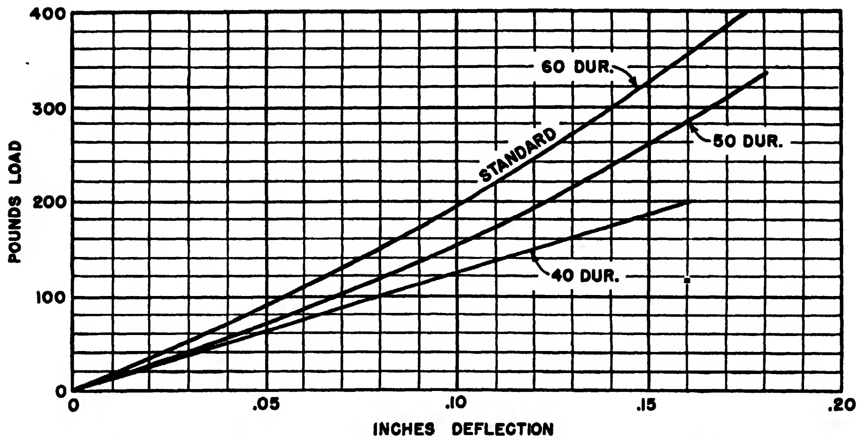


FIG. 4. This chart shows loading-deflection action of the smaller rubber button of the same two-part mounting to which Fig. 3 applies. (See also Figs. 17 and 18.)

would be more stable if mounted on an automobile by a rubber suspension unit placed directly above the center and another placed directly

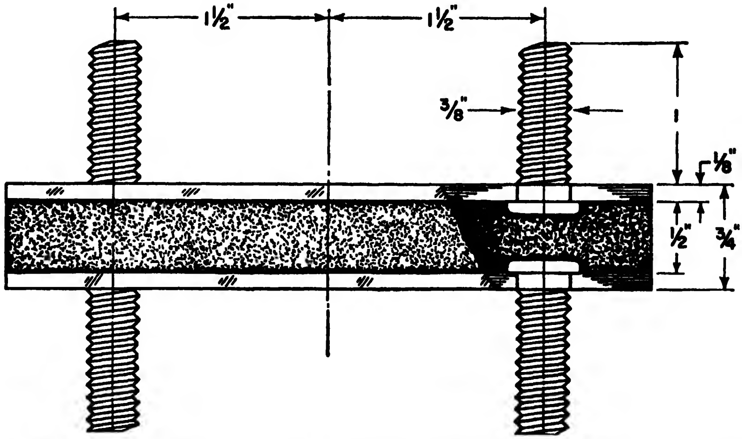


FIG. 5. Shear-type rubber mounting consisting of rubber of 40 durometer hardness sandwiched between two steel plates, to which it is bonded. Deflection in shear at 400-pound load, 0.17 inch. Minimum disturbing frequency at this deflection, 1,000 cycles per minute. For use at disturbing frequencies of 1,200 cycles and over, load should be reduced to 300 to 350 pounds for each mounting.

below than by two similar units mounted between the back of the receiver case and the wall.

An example of instability resulting from failure to place the mountings

in a proper manner occurs when a tall, top-heavy machine is isolated by installing suspension units beneath a narrow base. Often this cannot be avoided; and in such cases, the insulators should be spaced as widely as

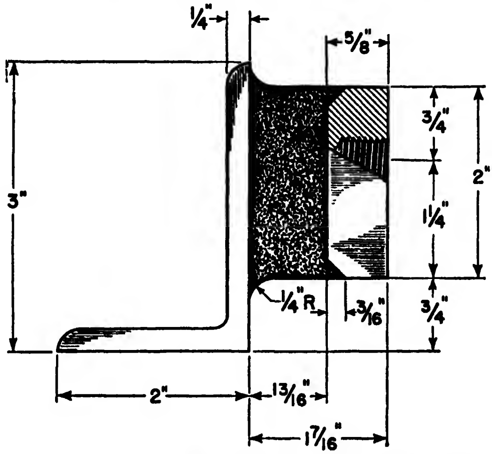


FIG. 6. Shear-type rubber mounting. Rubber durometer hardness, 40. Maximum recommended load, 75 pounds per inch of length. Deflection at this load, 1/2 inch. Minimum disturbing frequency at this deflection, 600 cycles per minute.

possible. A suspension will improve stability when placed with its long dimension parallel to the direction of the rocking motion. Sometimes a top-heavy machine mounted on isolation units has to be braced by rods

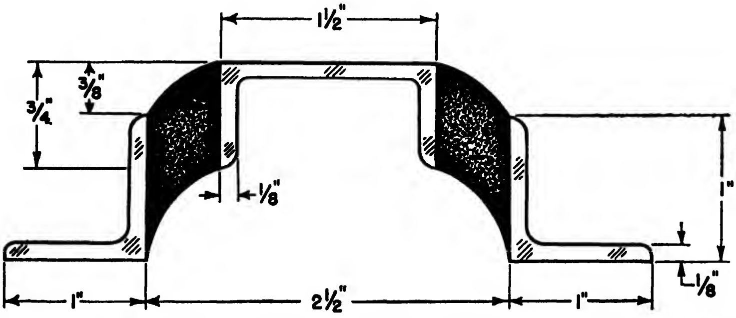


FIG. 7. Shear-type rubber mounting. Rubber durometer hardness, 45. Maximum recommended load, 50 pounds per inch of length. Deflection at this loading, 3/16 inch. Minimum disturbing frequency at this deflection, 1,000 cycles per minute. For frequencies of 1,200 cycles per minute and over, loading should be reduced to 40 pounds per inch of length. (See Fig. 8.)

running to rigid supports. Rubber vibration-absorbing units can be used between braces and machine. Standard vibration insulators can be mounted so they resist the rocking motion. Also, such insulators can

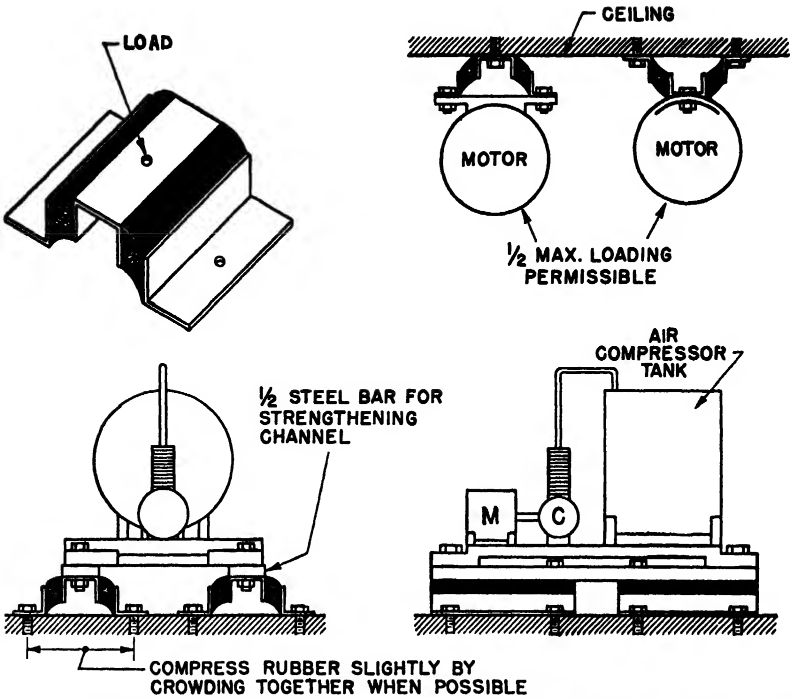


FIG. 8. Typical ways of employing the rubber vibration insulator shown in Fig. 7.

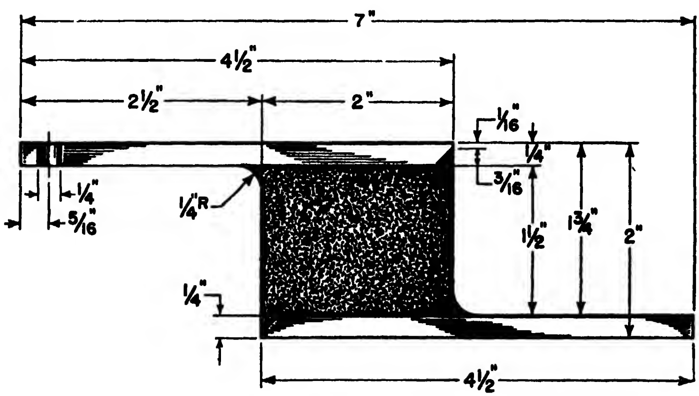


FIG. 9. Shear- or compression-type rubber mounting. Rubber durometer hardness, 40. Maximum recommended load in vertical shear, 80 pounds per inch of length. Deflection at this load, 1 inch. Minimum disturbing frequency at this deflection, 470 cycles per minute. (For frequencies of 550 per minute and higher, recommended loading is 60 pounds per inch.) Maximum recommended load in compression, 250 pounds per linear inch. Deflection at this load, 5/16 inch. Minimum disturbing frequency at this deflection, 850 cycles per minute.

be mounted to resist any other horizontal movement of a machine, in which positions they act as braces and do not support weight.

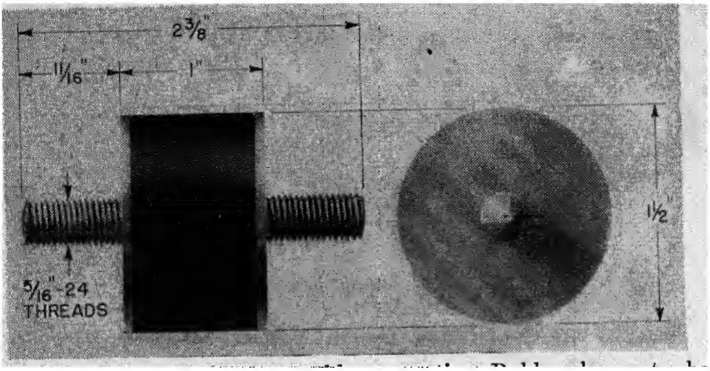


FIG. 10. Shear- or compression-type rubber mounting. Rubber durometer hardness, 40. Maximum recommended load in shear, 30 pounds. Minimum disturbing frequency at this load, 1,000 cycles per minute. Maximum recommended load in compression, 125 pounds. Deflection at this load, 0.175 inch. Minimum disturbing frequency at this deflection, 1,250 cycles per minute.

MAINTENANCE. Rubber vibration insulators require little care after installation. They should be protected against

1. Temperatures above 150°F.
2. Corrosion of their metal parts.
3. Wetting with oil. Simple metal shields usually can be installed to prevent this. A little oil spattering will do no appreciable harm.

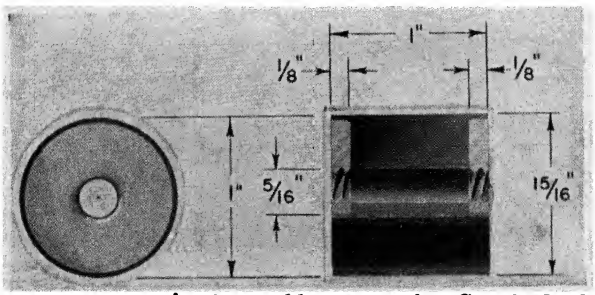


FIG. 11. Shear- or compression-type rubber suspension. Standard rubber durometer hardness, 40. Maximum load in vertical shear, 10 pounds. Deflection at this load, 5/32 inch. Minimum disturbing frequency at this deflection, 1,200 cycles per minute. Maximum recommended load in compression, 25 pounds. Deflection at this load, 1/16 inch. Minimum disturbing frequency at this deflection, 1,750 cycles per minute.

RUBBER SPRINGS VERSUS STEEL. The chief rival of the rubber spring is the older spring made of steel. Comparisons usually made by rubber technicians are

1. Damping factor is higher in rubber springs than in steel ones.

Inherent damping is desirable in cases of sudden impulses or resonance or in a wide range of frequencies, as in an engine that must be started and stopped and run at variable speeds.

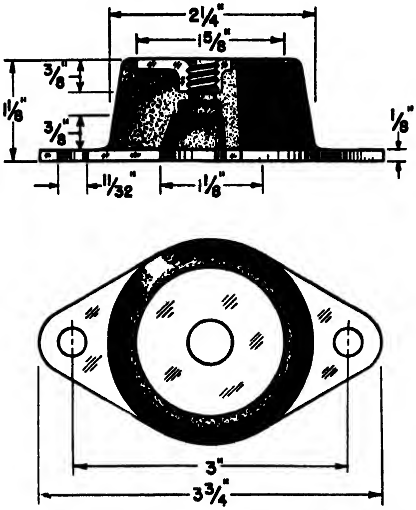


FIG. 12. Compression-type rubber mounting designed specially for isolating exhaust and intake fans. Rubber durometer hardness, 40. Maximum recommended load, 175 pounds. Deflection at this load, 3/16 inch. Lowest disturbing frequency should be 1,000 cycles per minute.

2. Rubber is able to store large quantities of energy for a given volume, while steel stores less.

3. Rubber is highly resilient.

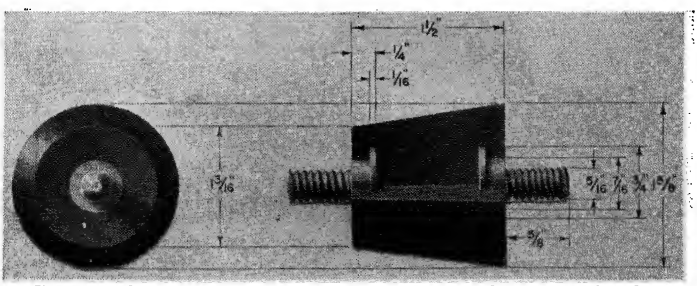


FIG. 13. Compression-type rubber mounting. Rubber durometer hardness, 40. Maximum recommended load, 110 pounds. Maximum deflection at this load, 3/16 inches. Minimum disturbing frequency at this deflection, 1,200 cycles per minute.

4. Steel springs may lack stability and require external support.

5. Sound transmission is greater through steel springs. With rubber, there is no metal-to-metal path for sound to travel.

6. Rubber requires no lubrication.

7. Rubber is affected by temperature changes to a greater degree than steel.

8. Crude rubber and American rubber such as GR-S are harmed by excessive oil. Oil-resisting compounds are used extensively.

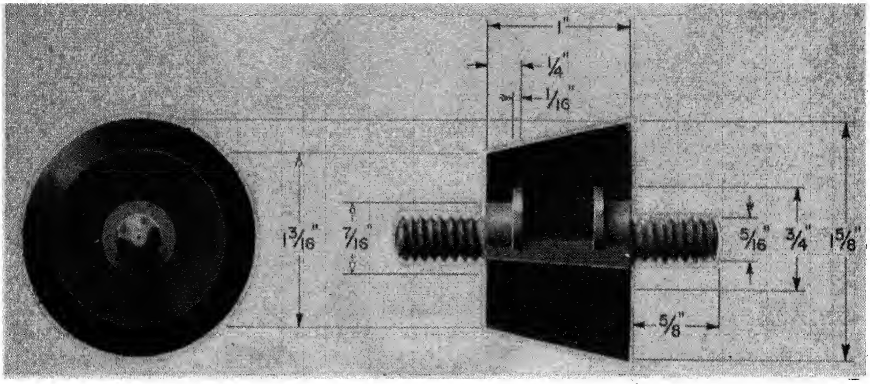


FIG. 14. Compression-type rubber mounting. Rubber durometer hardness, 40. Maximum loading, 150 pounds. Deflection at this loading, 5/32 inch. Minimum disturbing frequency at this deflection, 1,200 cycles per minute.

TYPES OF VIBRATION INSULATORS

There are a number of manufacturers who produce vibration-absorbing units made of rubber in combination with metal. Some typical forms of such insulators are

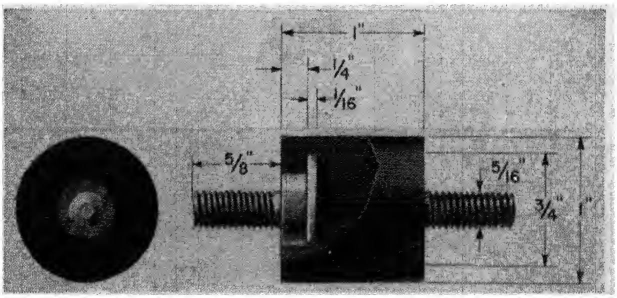


FIG. 15. Shear- or compression-type mounting. Standard rubber durometer hardness, 40. Maximum load in shear, 10 pounds. Deflection at this load, 5/32 inch. Minimum disturbing frequency at this deflection, 1,200 cycles per minute. Maximum load in compression, 50 pounds. Deflection at this load, 1/8 inch. Minimum disturbing frequency at this deflection, 1,350 cycles per minute.

1. Parallel steel plates equipped with mounting studs and joined together by a layer of resilient rubber. The rubber is vulcanized to the

metal with an adhesion strength greater than the strength of the rubber. The rubber is deflected in shear (Fig. 5).

2. Rubber unit vulcanized between a metal angle strip and a flat strip. Insulator can be cut to required length, thus adjusting it to the load it must bear. Rubber is deflected in shear (Fig. 6).

3. Similar to 2 but has two strips of rubber vulcanized between two angle strips and a central channel strip placed with open side down. Rubber is deflected in shear (Fig. 7).

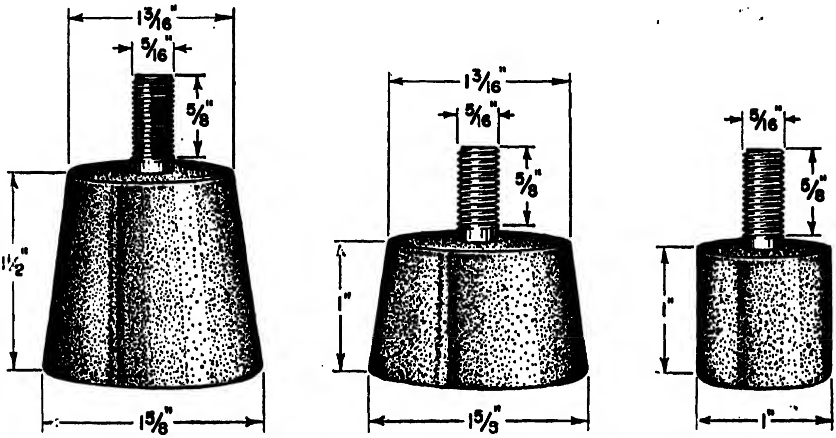


FIG. 16. Three compression-type rubber mountings. Characteristics: (*Left*) Maximum recommended load, 132 pounds. Maximum deflection at this load, 3⁄16 inch. Minimum disturbing frequency at this deflection, 1,200 cycles per minute. (*Center*) Maximum recommended load, 180 pounds. Maximum deflection at this load, 5⁄32 inch. Minimum disturbing frequency at this deflection, 1,200 cycles per minute. (*Right*) Maximum recommended load, 60 pounds. Maximum deflection at this load, ⅛ inch. Minimum disturbing frequency at this deflection, 1,350 cycles per minute.

4. Strip of rubber sandwiched between metal strips, one of which projects beyond one edge of rubber strip, the other beyond second edge. Rubber may be deflected in shear. Also may be used in compression with a maximum loading of 250 pounds per linear inch, which gives a deflection of 5⁄16 inch. Minimum disturbing frequency is 850 cycles per minute at 250 pounds per linear inch load (Fig. 9).

5. Tubular piece of rubber vulcanized between two concentric metal tubes, the larger of which forms housing. Mounted vertically, one metal tube being attached to machine to be isolated, other to foundation. Rubber is deflected in vertical shear. This unit is stable in all lateral directions.

6. Two metal disks with layer of rubber sandwiched between and vul-

canized to disks, which are equipped with threaded mounting lugs or holes. May be mounted in shear, compression, or tension (Figs. 10, 11).

7. Ring-shaped rubber unit vulcanized to metal base equipped with mounting ears and having a metal disk, with mounting hole, vulcanized to top or center. Used with rubber in compression, as in isolating fans (Fig. 12).

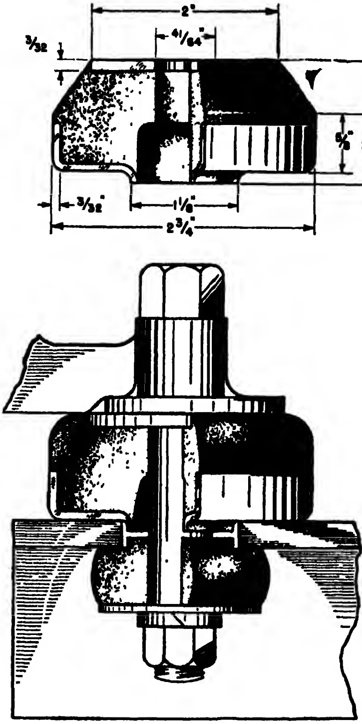


FIG. 17.

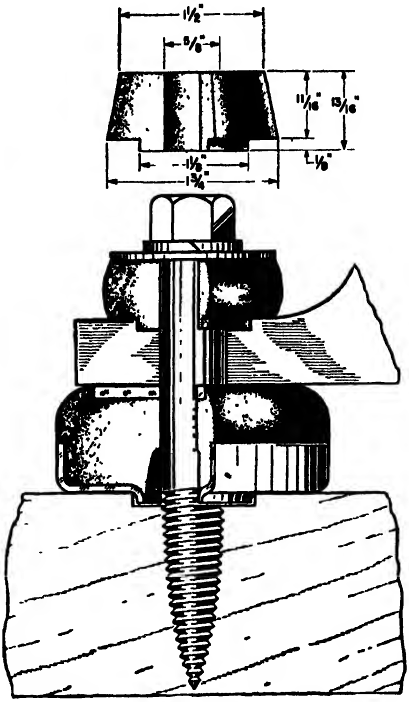


FIG. 18.

FIG. 17. Two-part, compression-type mounting designed particularly to isolate internal-combustion engines against torsional vibration at frequencies from 1,200 cycles per minute and upward. Normally the large metal-encased rubber part is of 40 durometer hardness, the smaller rubber part, 60 durometer. See Fig. 3 for loading and deflection of larger part, Fig. 4 for smaller part.

FIG. 18. Another way of mounting the rubber units shown in Fig. 17.

8. Rubber sandwiched between two concentric tubes or a tube and a solid rod and deflected in torsional shear.

In addition to the types of rubber springs just mentioned, countless other adaptions of the ability of rubber and similar elastic materials to absorb vibrations have been made. One of these consists of a thin layer of rubber sandwiched between two pieces of sheet steel, the resulting sandwich being used as a cushioning shim beneath lathe cutter bits and

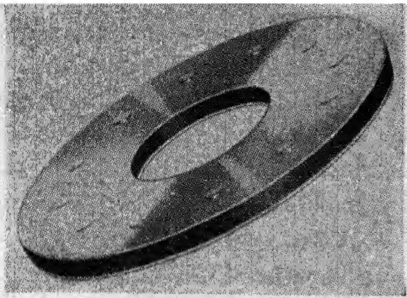


FIG. 19. Rubber wheel sandwich.

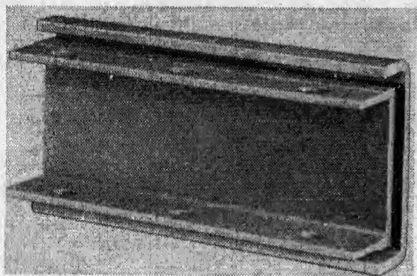


FIG. 20. Locomotive pedestal liner which uses springlike action of rubber.

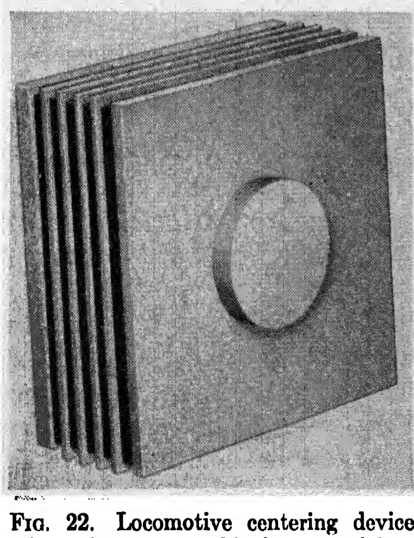


FIG. 22. Locomotive centering device using rubber as a cushioning material.

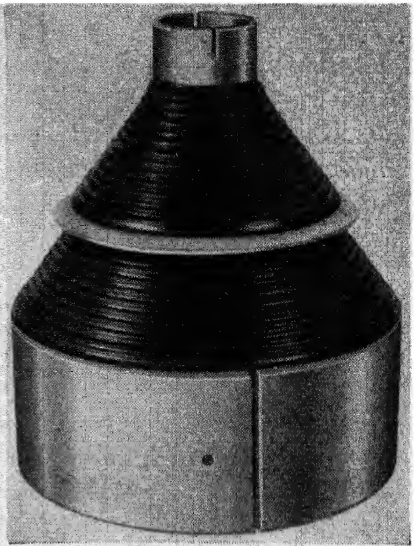


FIG. 21. Rubber streetcar spring.

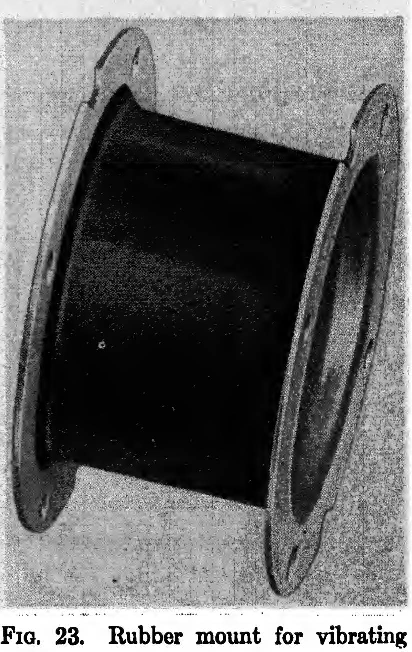


FIG. 23. Rubber mount for vibrating screen.

similar tools. Another application consists of a vibration-absorbing unit mounted on a lathe or grinder faceplate for absorbing tool chatter and gear train vibrations between faceplate and work-driving dog.

Rubber suspensions also include streetcar springs, which are large cylindrical vibration insulators with the rubber acting in shear between concentric steel tubular pieces; mounts for vibrating screens; streetcar wheel sandwiches; and locomotive pedestal liners and centering devices.

Torsilastic Rubber Spring

Although designed primarily as a suspension unit for vehicles, the Torsilastic rubber spring is suitable for many kinds of industrial applications. In an automobile or other vehicle, the rubber spring takes the place of conventional coil or leaf springs and their assembly of shackles, clips, and other metal parts. It provides an all-rubber barrier to vibration and shock attempting to travel between the car body and the wheels. Vehicles equipped with it exhibit a degree of road stability not associated with the use of metal springs.

Among the thousands of industrial uses of the Torsilastic spring are applications to office, porch, and other chairs and farm-machinery seats, physical exercising equipment, hand trucks, wheelbarrows, push carts, electric motors, stationary engines, built-in ironing boards, bicycles, truck tail gates, porch swings, juvenile tricycles and other vehicles, airplane landing gear, railway coaches and streetcars, conveyor belt suspensions, well-drilling equipment, and scientific apparatus.

Construction. A solid or tubular shaft and a cylinder or shell are placed concentrically and the space between them filled with an elastic rubber compound permanently bonded to both. The shell may be split lengthwise to facilitate manufacture; and when mounted, the halves are squeezed together to compress the rubber. Metal parts may be steel, cast iron or steel, brass, or aluminum.

Action. Either the shaft or the shell is mounted in a fixed position, and the other metal part arranged so it can rotate under applied load, the load being connected to the moving part by a moment arm (torque arm). The twisting action of one metal part in relation to the other makes the rubber behave like an endless shear sandwich and constitutes the entire springing movement.

Some Characteristics of Torsilastic Spring. (1) Does not squeak or rattle. (2) No bearings to be oiled or serviced. (3) Is unaffected by

mud, dirt, water. (4) Reduces vibration. (5) Eliminates friction. (6) Is simple in design and construction. (7) Has long service life. (8) Reduces noise level. (9) Absorbs shock or impact from all directions. (10) Elimi-

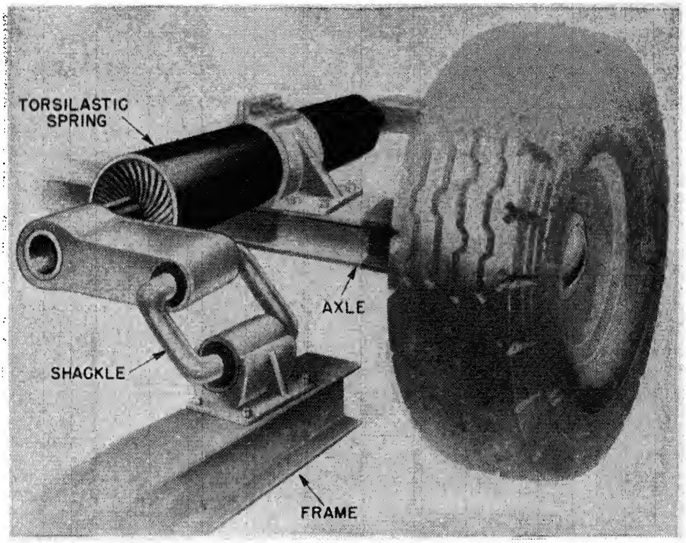


FIG. 24. Torsilastic rubber spring as used on a modern bus. The outer shell of the spring is clamped to the axle, while the central shaft is linked by a rubber-cushioned shackle to the bus frame. As the axle moves up and down, the rubber is twisted—much as you might twist your left forearm with your right hand.

nates danger of sudden break or failure. (11) Provides complete rubber cushion between suspended mass and foundation. (12) Has a slight

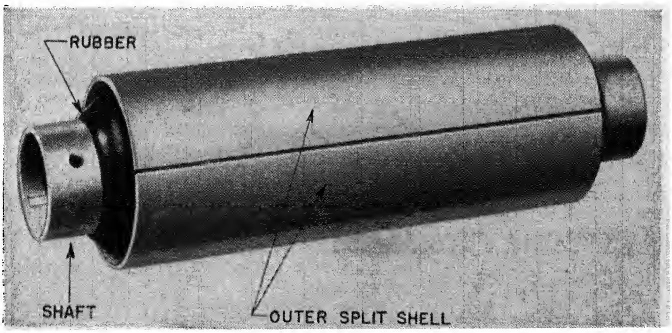


FIG. 25. Torsilastic rubber spring consisting of a cylinder of soft rubber bonded to a tubular steel shaft and an outer split shell.

damping action. (13) Is easily adjusted to regulate machine height and clearance. (14) May be used as a hinge that never squeaks or needs oiling.

In applications to industrial equipment, Torsilastic springs generally can be mounted much like other kinds of rubber suspension units. A wide range of conditions and requirements can be met by varying the design of the spring and the length of the moment arm by which the torsional load is imposed.

STATIC-LOAD DEFLECTION. This is the amount the spring is deflected under static load and is the distance through which the outer end of the

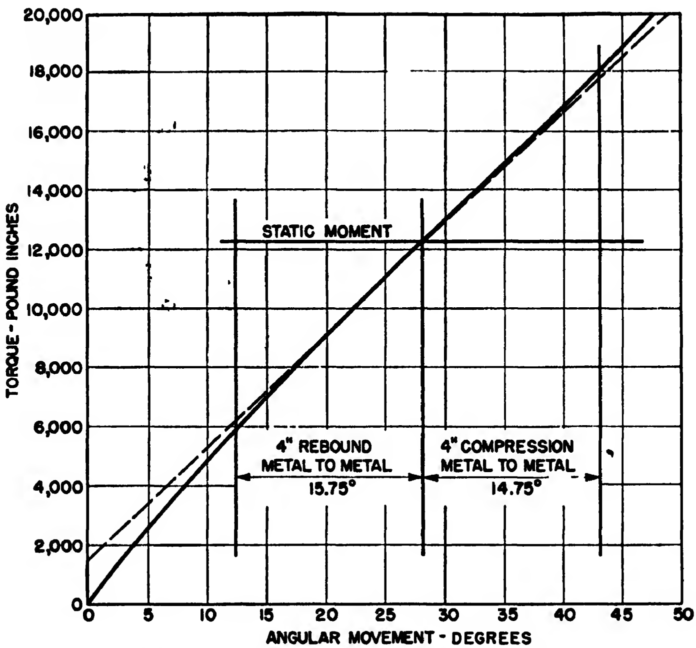


FIG. 26. Torsional loading curve for rubber spring. At or near the static load point, the curve is practically a straight line, and although there is a typically steeper slope at light loads and a stiffening at high angles in some designs, the spring has a practically constant rate throughout the range useful in suspension.

moment arm must move before the weight is wholly supported. (For a passenger automobile, this deflection is usually 7 to 12 inches.) Deflection may be expressed in degrees.

LENGTH OF MOMENT ARM. This often is limited by the space available for the spring unit. The longer the arm the smaller the angle through which the rubber must be stressed in torsional shear.

LOADED MOMENT OR TORQUE. This is the load in pounds multiplied by the length of the moment arm in inches (end of arm to axis of rotation).

TORSIONAL RATE OF SPRING. This can be determined by dividing static moment (in pound-inches) by angle of static deflection (in degrees).

To meet any fixed set of requirements, the spring can be made in a variety of designs; *i.e.*, a long, slender spring may be designed for the same static load and torsional rate as a short, fat one.

TORSIONAL LOADING. If the torque applied through the moment arm, in pound-inches, is plotted against angular movement of the arm, in degrees, a curve like that shown in Fig. 26 is obtained.

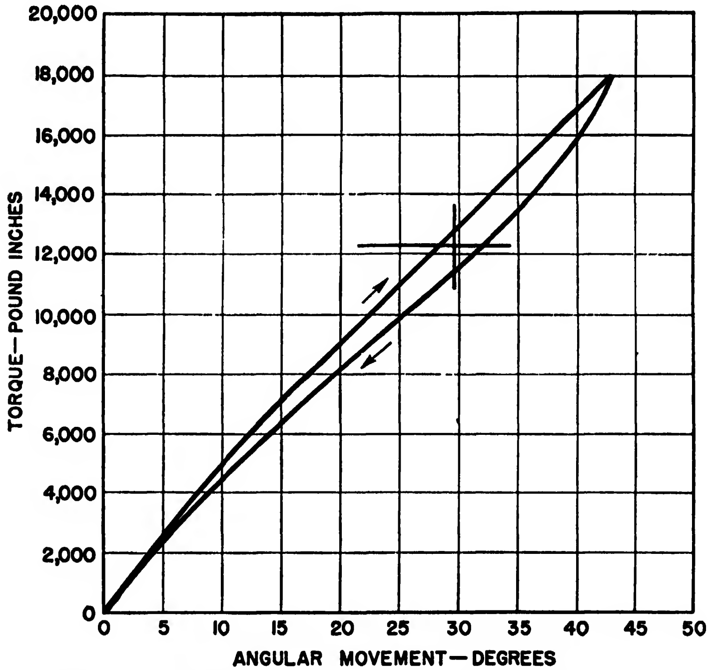


FIG. 26. Torsional loading and unloading curve. The area between the two curves represents hysteresis or energy absorbed during the cycle. This apparent loss is modified by the time required for the cycle and to a lesser degree by the Joule effect.

TORSIONAL LOADING AND UNLOADING. If a Torsilastic spring is subjected to static load and unload (by adding and removing weights and noting angular movement) and the results plotted, the curve shown in Fig. 27 is obtained. The unloading and loading curves do not coincide, and the area between them represents the hysteresis loss. This loss is modified by the frequency of the cycle.

PENDULUM ACTION. If a Torsilastic spring is mounted, and if a weight suspended from the end of the moment arm to produce a static load torque is pulled down and released, it will oscillate much in the same manner as a weight suspended from a coil spring, the rate of oscillation

being the natural, free, or resonant frequency. This can be converted into dynamic torsional rate by means of the pendulum formula

$$d = \left(\frac{188}{f}\right)^2$$

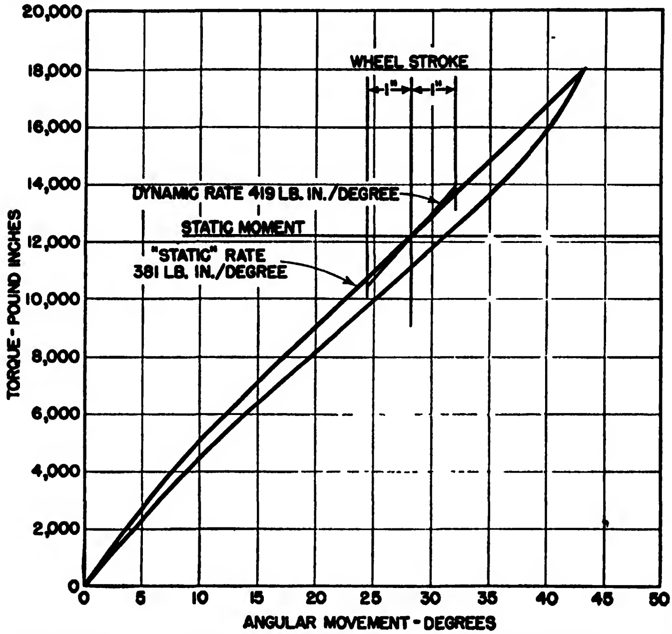


FIG. 28. Comparison of dynamic and "static" cycles of a Torsilastic rubber spring. The "static" loading curve shown for the whole range of spring deflection was obtained by loading weights on a beam to produce variable moments on the spring; several seconds elapsed between readings, and the complete cycle required 2 to 5 minutes. Under these conditions the resultant "static" stress-strain curves have at least 20 per cent lower slope at normal loaded deflection than the slope of the dynamic curves.

where f = oscillations per minute

d = deflection = length of arc, in inches, through which moment arm turns in supporting average moment

$$\text{Unit torsional rate} = \frac{\text{Moment}}{\text{angle subtended by } d}$$

DAMPING EFFECTS. The hysteresis loss for Torsilastic springs, like other types of rubber springs, is so small when the dynamic stroke is short that damping action is negligible. When the stroke is considerable, there is noticeable damping. However, it is sometimes necessary to use

shock absorbers in conjunction with Torsilastic springs in automotive and similar applications.

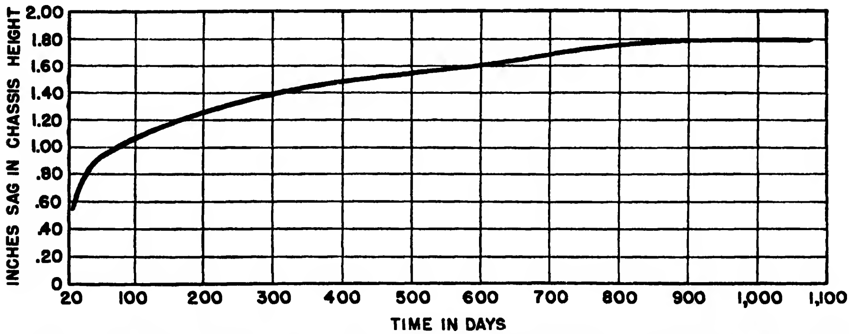


Fig. 29. This graph shows the creep or set of a Torsilastic rubber spring in a test covering three years. The spring carried a static shear load of 135 psi on the outside diameter of the shaft.

Creep. Under constant static load, a Torsilastic spring exhibits some creep. On a test automobile driven 36,000 miles over a period of 2½ years, the extent of chassis sag in inches was most pronounced during the first

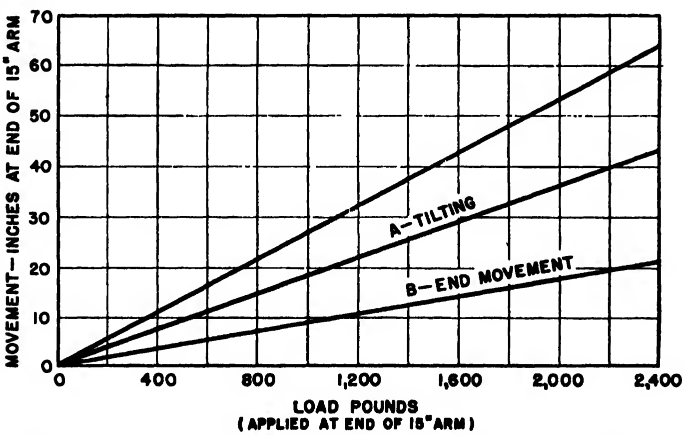


Fig. 30. Deflection of torsional rubber spring under tilting and axial forces. In an automotive application especially, the slight elasticity indicated by the curves is desirable in order to reduce the harshness of the ride. Total amounts of such displacements can be controlled over a considerable range by proportions selected for the spring. Upper curve represents $A + B$.

few days, and for the entire period amounted to about 1.2 inches, as shown in Fig. 29.

Typical deflections under tilting and axial forces on an automotive Torsilastic spring are shown in Fig. 30.

In Fig. 31 is shown the displacement of the same spring under radial deflection.

Static shear stress allowable between inner member (shaft) of spring and the rubber depends on the nature of the suspension. Suggested shear stresses for passenger automobile suspensions are approximately 120 psi; for machinery, approximately 60 psi.

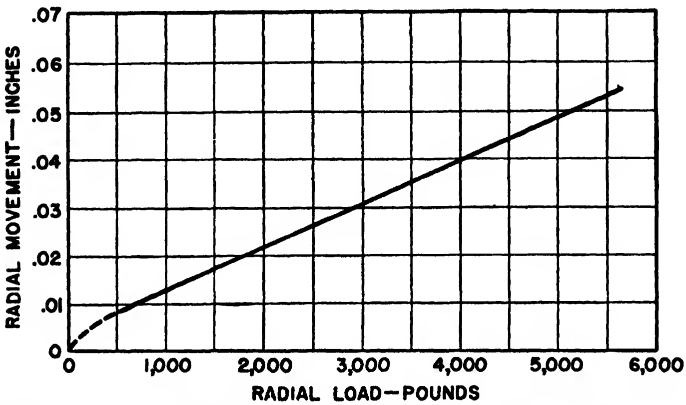


Fig. 31. Displacement of torsional rubber spring under radial deflection.

The foregoing figures may be modified by the hardness of the rubber stock used. Deflection of soft rubber is greater at a given load and torque arm length than that of harder compounds. Usually the range of compound hardness is 40 to 60 durometer, with 45 used for most calculations for crude rubber and 50 for American-rubber compounds.

Spring Shaft. This is dimensioned to provide for the required static moment without exceeding the unit shearing stress limits of the rubber-to-metal bond. Various combinations of rubber length and diameter at the shaft can be used.

Thickness of Rubber. The mathematical analysis of the functions of rubber thickness and spring rate is

R_1 = inside radius of rubber
R_2 = outside radius of rubber
r = radius to any element
L = length of bushing
S = unit shearing stress
T = torque
ψ = angular deformation
G = shear modulus
$\theta = S/G$ (for small angles)

$$d\psi = \frac{\theta dr}{r}$$

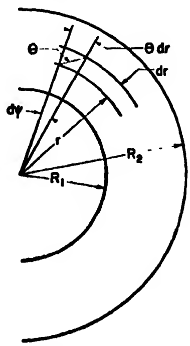


Fig. 32.

For any given torque,

$$T = 2\pi r \times S \times r \times L$$
$$= 2\pi r^2 SL$$

Since r^2S is a constant,

$$S = \frac{R_1{}^2S_1}{r^2}$$
$$d\psi = \frac{S}{G}\frac{dr}{r} = \frac{R_1{}^2S_1dr}{r^2Gr}$$
$$\psi = \frac{R_1{}^2S_1}{G}\int_{R_1}^{R_2}\frac{dr}{r^3}$$
$$\psi = \frac{R_1{}^2S_1}{2G}\left(\frac{1}{R_1{}^2} - \frac{1}{R_2{}^2}\right)$$

Angular deformation,

$$\psi = \frac{T}{4\pi LG}\left(\frac{1}{R_1{}^2} - \frac{1}{R_2{}^2}\right)$$

The shear modulus G for the rubber compound, by appearing in the equations involved in such an analysis, creates a difficulty. The quantity G is commonly defined by the slope of the tangent to the shear curve for small amplitudes of movement. However, such a tangent (shown in Fig. 33) does not correspond to that of the portion of the curve representing actual service-stress ranges.

Graphical Analysis. In Fig. 33, the relations between spring rate and rubber thickness have been treated graphically. The rubber is assumed to be divided into layers each having a thickness equivalent to 5 per cent of its inside radius. With the spring unloaded, a radius drawn through the rubber will pass through a series of imaginary points. When load is imposed and the rubber given a torsional deflection, these points are shifted in such a way that a line drawn through them will form the curve marked "element that is radial at no load." The shearing stress at a point on the curve varies inversely as the square of the radius to that point. One graph for each rubber compound will generally cover all practical design requirements.

The inside arc represents the highest shear stress (120 psi in Fig. 33). When a spring for lower static stress is desired, the arc that represents that stress is selected, and its radius becomes the new inside radius of the rubber cylinder.

Angular deflection depends on rubber thickness and shearing stress. Thickness of the rubber wall is generally expressed as a percentage of the inside diameter of the rubber cylinder (outside diameter of the spring shaft). If a number of Torsilastic springs having different diameters but

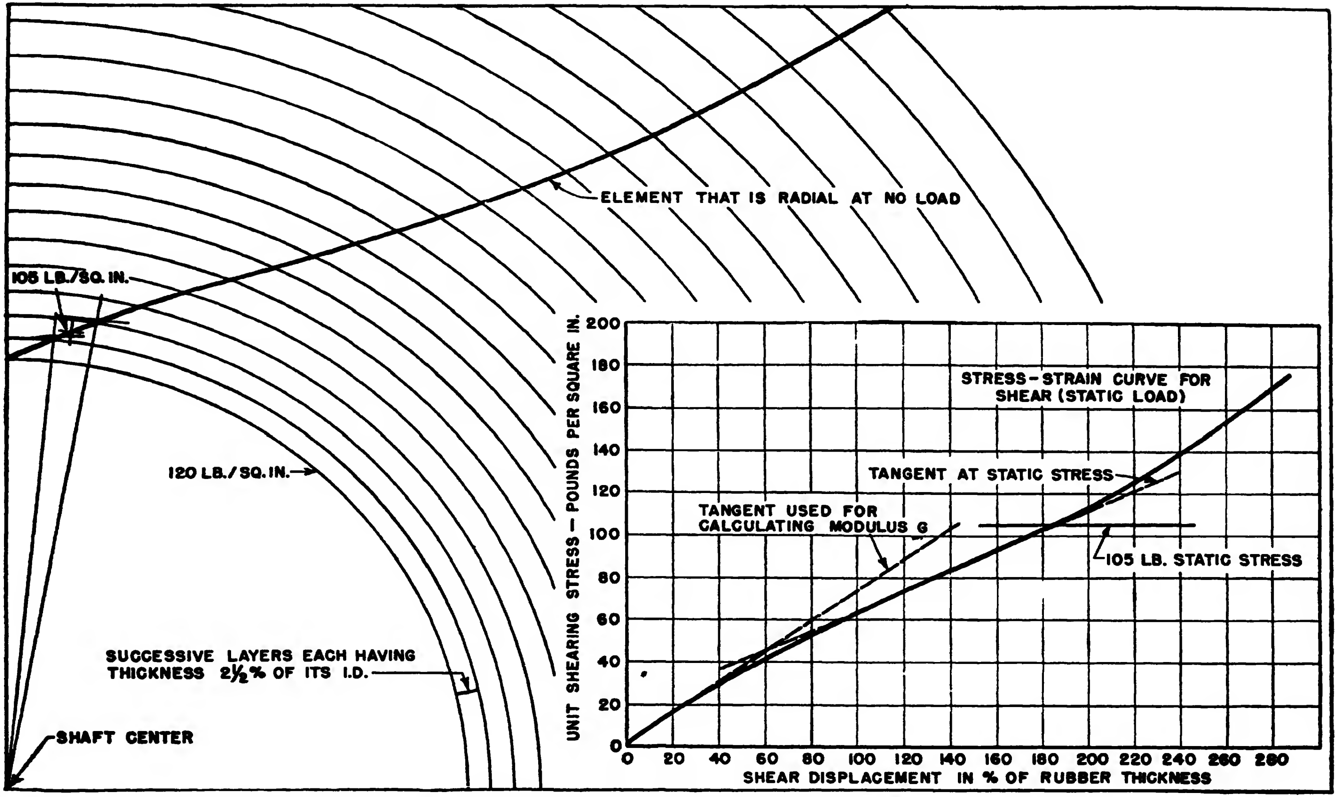


FIG. 33. Section through a simple rubber Torsilastic spring under torsional shear. The curve at lower right shows stress-strain characteristics of a sample of the same rubber compound subjected to pure or "straight-line" shear, the sample being sandwiched between flat plates (to which it is vulcanized) and stressed by parallel movement of the plates.

each with a rubber wall thickness that is, say, 25 per cent of the rubber inside diameter are rotated through the same angle, the shearing stress where the rubber is bonded to the spring shaft will be the same in each spring. This holds for all other wall percentages.

WALL THICKNESS. Radial thickness of the rubber cylinder wall can be calculated also from the spring's angular wind-up under static load or its angular rate. Figure 8 shows the wind-up plotted against stress for

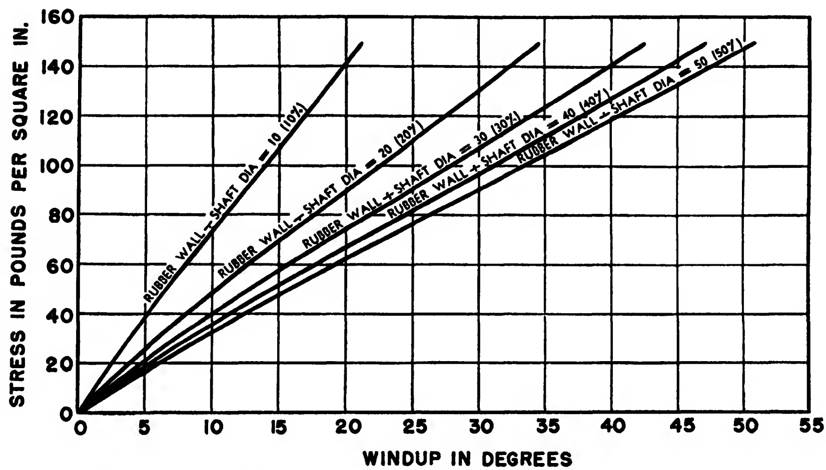


FIG. 34. Torsilastic spring windup. The curves show static conditions where windup occurs very slowly or where spring is held for long periods with a fixed windup. When the spring is flexed through a full cycle in a second or less, it shows a stiffer rate called the "dynamic rate." The ratio between static and dynamic rates depends on the rubber compound: for crude rubber of 45 durometer hardness, this ratio may be assumed to be 1.25; for American rubber of 50 durometer, the ratio may be assumed to be 1.50.

springs having wall thicknesses from 10 to 50 per cent of the shaft diameter and for stock of 42 durometer hardness. For 50 durometer stock, multiply the stress at a given wind-up angle by 1.37; for 55 durometer, by 1.62. Thus, for a wind-up of 20 degrees and a maximum shearing stress of 60 psi in a spring having a shaft diameter of 2 inches, a wall thickness for a 42-durometer natural-rubber compound would be 50 per cent of the shaft diameter, or 1 inch. This is for static conditions where the wind-up occurs very slowly or the spring is at rest for long periods. Dynamic conditions exist when the spring is flexed faster, and the difference between dynamic and static varies with the compound. For most natural-rubber compounds, the dynamic rate will be approximately 120 per cent as stiff as the static rate, for a range of frequencies of, say, 4 seconds per cycle down to several cycles per second.

Maximum Stress. Stress range, frequency of occurrence of maximum conditions, and other factors determine the maximum shear stress. Stresses as high as 300 psi have been used successfully, but recommendations usually are for a lower maximum figure.

Life of Torsilastic Spring. The rubber is exposed at the ends, but this has been found to have such negligible effect on the life of the

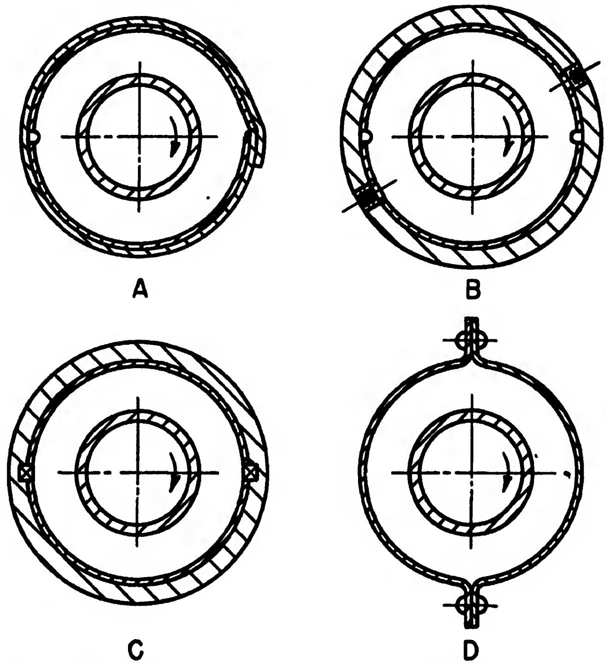


Fig. 35. A Torsilastic rubber spring may have its outer shell split into two 180-degree segments. These are pressed into a housing to assemble the spring. Methods of locking the spring in its housing include (*A*) a tangential tongue, (*B*) hollow-head set screws, and (*C*) locking keys. The flanged split shell in (*D*) requires no housing.

rubber compound that no attempts are made to provide a cover. Spring life depends on such factors as the range of stress variations. Reversing the stress direction, so that part of the cycle is at a plus psi and part at a minus, affects life more than when the same stress range is in one direction.

Eccentric Loading. This should be avoided where possible, and the spring mounted so the load applied through the torque arm is centered with respect to the spring length. Thin-walled springs (not over 20 per cent rubber-wall thickness) resist eccentric loading better than those having thick walls. Ability of the Torsilastic spring to absorb some degree

of impact from any direction helps it to resist eccentric forces and to make the unit self-centering.

SUMMARY. Steps involved in Torsilastic spring design include

1. Find the static spring load and deflection and select an arbitrary moment arm length.
2. Calculate the torque on the spring when the suspended machine is at rest (static moment).
3. Calculate the static torsional rate

$$\left(\frac{\text{static moment}}{\text{angle of deflection}}\right).$$

4. Select the static shear stresses to be applied to the rubber at the surface of the shaft (inside diameter of rubber cylinder). For machinery, this is usually approximately 60 psi. Stresses of 120 psi and more are used successfully in some automotive applications.
5. Determine the combination of spring length and shaft diameter that will produce the required torque and total static shear stress in the rubber where it is bonded to the shaft.
6. Determine the thickness of the rubber cylinder wall.

Once installed, a Torsilastic suspension should require no attention for many years other than an occasional checkup and possible adjustment to overcome slight settling of the suspended mass. The rubber, unless oil-resisting, should be protected from excessive oil.

The matter of shape and method of attachment of the torsion arm and of mounting the spring itself is subject to wide variations. In Fig. 36 are shown four methods of mounting a split-shell Torsilastic spring. The two halves of the shell are forced together, and the spring pushed into the housing, where the shell is locked against rotation by some means such as keys or set screws. In *D*, the spring shell forms its own housing.

Chapter 11

HARD RUBBER

One spring day in 1908, a man surprised his neighbors in a West Virginia farm community by appearing with an 8- by 10-inch view camera and announcing that he was ready to photograph anything from farm stock to family reunions. He had bought the camera from a city photographer, and the outfit that went with it included a hard rubber tray for developing plates or prints. Thirty-eight years later, that same tray was still in existence in his son's basement darkroom. It was a bit battered on one corner, where it had landed in a nose dive to a concrete floor, and its surface was roughened, either from some nonphotographic chemical that once had been poured into it or from sheer "erosion." But the tray was still serviceable enough to be kept on hand as an emergency piece of equipment. Such is the durability of hard rubber!

True hard rubber, as distinguished from soft rubber which may have almost as great durometer hardness, is a compound whose hardness is the result of a chemical reaction between rubber and a large proportion of sulfur. Hard rubber requires the use of 20 to 30 per cent sulfur, so as to "saturate" the rubber and destroy its chemical reactivity, whereas soft rubber is vulcanized with less than 10 per cent and usually from 1 to 5 per cent sulfur. The so-called "soft" rubbers may be made virtually as hard by the addition of fillers, but they do not possess the special properties that make true hard rubber desirable for many purposes. Like its softer relatives, hard rubber may be any of an almost endless variety of compounds because of the infinite combinations that can be made with rubber, sulfur, and other compounding ingredients. Therefore it is possible for a manufacturer of hard rubber to produce many materials for meeting special problems encountered by the design engineer. Hard-rubber compounds may be made of crude rubber, reclaimed rubber, or various American-made rubbers.

Properties of Hard Rubber

Hard rubber was one of the first of the engineering materials that are now commonly grouped as plastics. Its properties are such that it still

holds its own among hundreds of newer plastic materials—indeed, certain of its properties are unique. In comparing hard rubber with the various plastics, it should be kept in mind that rubber is a thermosetting material while many of the others are thermoplastic.

A considerable number of barbers are said to have discontinued the practice of singeing hair during the Second World War because they could not buy hard-rubber combs, which had become standard singeing accessories at least as early as the First World War. Besides having a "feel" possessed by no other kinds, hard-rubber combs will withstand the heat of a singeing flame. Combs made of substitute materials often have a habit of softening and distorting when near a flame. Superior "feel" and good heat resistance are therefore characteristics that can be built into hard-rubber products. Some other general qualities include

1. Attractive appearance.
2. Excellent moldability.
3. High tensile strength.
4. Easily polished to a high luster.
5. Easily cut, drilled, tapped, turned, threaded, ground, and polished.
6. Does not conduct heat. Is transparent to heat rays (infrared radiation).
7. Electrical resistance is high. Has good high-frequency characteristics.
8. Resists electrolytic action.
9. Has high resistance to acids, alkalies, corrosives, gases, and other chemicals.
10. Water absorption very low.

More specific properties attainable in hard crude-rubber compounds are listed below. In considering these characteristics, it must be remembered that the infinite variety of ingredient combinations makes any listing either an indication of the range of attainable properties or a sampling of some of the more common ones.

Properties of Hard-rubber Compounds

Tensile strength: 1,000 to 9,000 psi.

Compressive strength: 10,000 to 15,000 psi.

Transverse (shear) strength: 7,500 to 16,000 psi.

Impact strength: 10 to 90 inch-pounds per square inch at 32°F.

Elongation: 1 to 50 per cent. When elongation is above 10 per cent, it indicates a slightly soft compound.

Specific gravity: 1.13 to 2.00. Can be increased by adding weighting materials.

Temperature resistance: Softens at 125 to 200°F.

Moisture resistance: Absorption of water is as low as 0.01 per cent during 24 hours' immersion at 70°F.

Aging resistance: Deterioration with age is negligible, in contrast to soft rubbers. Test samples have shown no aging after more than 30 years.

Chemical resistance: High. Hard rubber is not wholly resistant to the following chemicals: aniline, benzol, carbon bisulfide, chloroform, ethylene dichloride, nitric acid over 16° Be′, sulfuric acid over 50° Be′.

Hard rubber is not affected by the following: nitric acid below 16° Be′, sulfuric acid below 50° Be′; any concentration of acetic acid, citric acid, copper sulfate; corrosive gases such as hydrogen chloride; solutions of chlorides including calcium, ferric, ferrous, stannic, stannous, and zinc chloride; gasoline; greases; oils; hydrochloric acid; hydrofluoric acid; hydrofluosilicic acid; kerosene; phosphoric acid, tannic acid.

TABLE 1. ELECTRICAL CHARACTERISTICS OF A TYPICAL HARD RUBBER

Dielectric strength, volts per mil, measured on ⅛₂-in. sheet. . . .	650
Dielectric constant, 1,000 cycles, 5 volts, 79°F, 29 % RH.	3.00
Phase difference angle (deg at 1,000 cycles, 5 volts). . .	0 23
Surface resistivity, megohms/cm.², 77°F, 39% RH . . .	9×10^{11}
Volume resistivity, megohm/cm.³, 77°F, 39% RH . . .	6×10^{11}

Some Limitations of Hard Rubber

Inflammability: Will burn, although not readily ignited.

Thermal softening: Standard grades soften at 125 to 150°F, others up to 200°F.

Cold flow: Under a continued, localized pressure, hard rubber exhibits a slight cold flow or permanent set.

Warping: Condition of support or mounting may permit or cause warping unless the design incorporates precautions necessary to prevent it.

Shrinkage: Because of slight variations in shrinkage, machining is advisable where highly accurate dimensions or fits are required. Shrinkage in molds may necessitate polishing and buffing (at added cost) to produce a high-gloss finish.

Forms and Applications

The properties that can be compounded into hard rubber make it superior in many industrial applications. However, its most valuable characteristics are its chemical and electrical resistance. Numerous hard-rubber parts are used in radio, radar, X-ray, and other electrical equipment. Its chemical resistance makes it suitable for parts used in

rayon-making, bleaching, dyeing, and chemical-industry equipment and in the handling and making of inks. Both chemical resistance and electrical resistance are required in such applications as storage batteries and electrolytic equipment.

Molded Articles

Shapes ranging from the simple to the highly complicated are produced by molding. The procedure is much the same as that for soft-rubber products, except that little or no undercutting is permissible with hard rubber, which is easily damaged at the temperature at which it is removed from the mold. Designers and others wishing to use hard-rubber molded parts should consult experienced rubber technicians as early in the product-development stage as possible. The manufacturer should be supplied with detailed drawings, an appraisal of service conditions, and an indication of the quantity of parts desired.

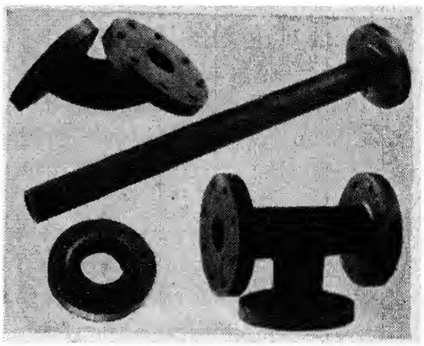


Fig. 1. Typical forms of flanged hard-rubber pipe and fittings. Flanges screw on the straight section of pipe, while the 90-degree ell and tee have integral flanges.

Grades of Hard Rubber

Besides the "bone-hard" grades, semihard compounds are available that are superior where some softness is desirable. These semihard materials are true hard rubbers, not hard grades of soft compounds. In measuring hard rubber density, the type D Shore durometer is commonly used. Its indentor has a needle point, and its scale is not comparable to that of the Type A durometer used for soft rubber.

Grade	*Durometer D Hardness*
Semihard	30–65
Hard (ebonite)	65–95

Combinations

Hard rubber is combined with other materials to give it greater rigidity or to impart other desirable features.

Hard and Soft Rubber. By molding, soft and hard rubber can be combined to produce parts in which the softer material provides a cushioning action while the hard compound resists destructive chemical action or some other factor, *e.g.*, hard rubber over a soft, yielding layer in chemical tank lining; caster and carpet-sweeper wheels having hard cores, soft treads.

Anode-covered Parts. A metal part, even when of intricate shape, can be covered uniformly with a hard or semihard compound by the Anode process (see Chap. 4). Screens, perforated steel plates, perforated metal baskets, impellers, and filter press plates are among the products exhibiting such combinations of metal and rubber.

Vulcalock. Hard rubber can be joined by the Vulcalock process to most metals, with a bond whose strength is greater than that of the rubber itself.

Reinforced Hard Rubber. Often it is desirable to make a hard-rubber part stronger by reinforcing it with wood or metal. The reinforcing piece can be combined with the rubber during molding or can be joined to it by cement or with fasteners such as self-tapping screws.

Combination with Plastics. Hard rubber can be combined with plastics such as phenol-formaldehyde in order to make use of the best properties of both materials, *e.g.*, an insulator for an X-ray machine for use in the tropics, where a plastic core gives greater heat stability than hard rubber alone while the rubber provides better electrical properties than the plastic alone.

Pipe and Fittings

Hard-rubber pipe and fittings are used widely by chemical industries and have for years been considered superior to various substitute materials because of a combination of desirable properties. Industries using hard-rubber pipe include manufacturers of rayon, gunpowder, gases, food products, acids and alkalies, dyes, medicines, dry batteries, and photographic materials.

Kinds of Pipe. There are two general types or constructions of hard rubber pipe and fittings:

1. Threaded pipe and fittings for "standard" service. Weight, about 20 per cent that of rubber-lined steel pipe of corresponding size.

2. Flanged pipe and fittings for heavy-duty requirements. Weight, about 33 per cent that of rubber-lined steel pipe.

Pressure-temperature Range. The figures for one manufacturer's line may be considered typical:

TABLE 2. STANDARD-WEIGHT PIPE DIMENSIONS

Nominal size, in.	*I.D., in.*	*O.D., in.*	*Wall thickness, ft*	*Max. length, ft*	*Approx. wt, lb/ft*	*Pipe screws into fitting, in.*
1/4	1/4	17/32	9/64	10	0 093	5/16
3/8	3/8	11/16	5/32	10	0.140	7/16
1/2	1/2	27/32	11/64	10	0 195	9/16
3/4	23/32	1 1/16	11/64	10	0.263	9/16
1	31/32	1 5/16	11/64	10	0.332	11/16
1 1/4	1 7/32	1 11/16	15/64	10	0.575	11/16
1 1/2	1 15/32	1 15/16	15/16	10	0 675	3/4
2	1 7/8	2 3/8	1/4	10	0.895	3/4
2 1/2	2 1/4	2 7/8	5/16	10	1 35	1 1/8
3	2 3/4	3 1/2	3/8	10	1 98	1 3/16
4	3 11/16	4 1/2	13/32	10	2.81	1 5/16

Manufacturing tolerances on sizes between 1/4 and 1 in. are approximately 1/64 in.; between 1 and 2 1/2 in. are 1/32 in. and on larger sizes 3/64 in.

Standard iron-pipe threads used on all standard hard-rubber pipe and fittings.

TABLE 3. HEAVY-DUTY PIPE DIMENSIONS

Nominal size, in.	*I.D., in.*	*O.D., in.*	*Wall thickness, in.*	*Max. length, ft*	*Approx. wt, lb/ft*
1	3/4	1 5/16	9/32	10	0 49
1 1/4	1	1 11/16	11/32	10	0.78
1 1/2	1 1/4	1 15/16	11/32	10	0 92
2	1 1/2	2 3/8	7/16	10	1 43
2 1/2	1 7/8	2 7/8	1/2	10	2 04
3	2 1/4	3 1/2	5/8	10	3 03
4	3	4 1/2	3/4	10	4 74
6	4 7/8	6 5/8	7/8	10	8 50

TABLE 4. DIMENSIONS OF HEAVY-DUTY FLANGES, INCHES

Nominal size	*A*	*B*	*C*	*E*	*F*	*Size bolts*	*No. bolts*
1	4 1/2	3 1/4	...	11/16	...	1/2	4
1 1/4	5	3 3/4	...	3/4	...	1/2	4
1 1/2	6	4 1/2	2 7/8	13/16	1 1/8	5/8	4
2	6 1/2	5	3 3/8	7/8	1 1/8	5/8	4
2 1/2	7 1/2	5 7/8	4 1/8	1	1 1/4	3/4	4
3	8 1/4	6 5/8	4 7/8	1 1/8	1 1/2	3/4	8
4	10	7 7/8	5 1/2	1 1/4	1 3/4	3/4	8
6	12 1/2	10 5/8	8 1/2	1 7/16	2	3/4	12

Threaded, normal-duty pipe: Pressures to 50 psi at normal (70°F) temperature.

Flanged, heavy-duty pipe: Pressures to 80 psi at normal temperatures,

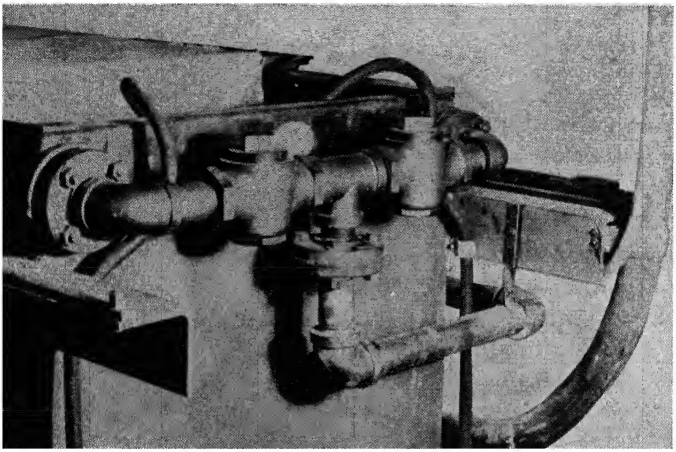


FIG. 2. An installation of hard-rubber pipe and fittings.

pressures to 50 psi at temperatures to 150°F. Flanged pipe is specified for all permanent installations.

Heavy-duty plug cocks: Up to 50 psi at normal temperatures; for higher temperatures, reduced pressure is necessary.

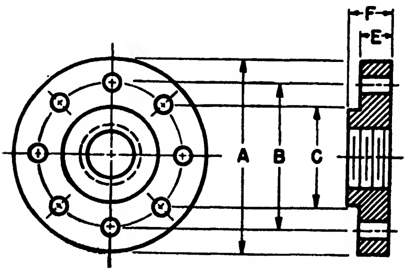


FIG. 3. Hard-rubber flange dimensions.

Temperature range: Normally up to 150°F. For higher temperatures, special, somewhat more costly compounds are available.

HANDLING AND INSTALLING

THREADING. See the section entitled The Working of Hard Rubber, page 240.

GASKETS. Soft-rubber gaskets are used between flanges, etc. These may be compounded to resist specific liquids.

TIGHTENING FLANGES. A flange is screwed on each pipe end, and a pair of flanges is held together by bolts. Usually a flange can be tightened sufficiently by hand while the pipe is held by a strap wrench, or a similar wrench can be used on the flange, too.

EXPANSION AND CONTRACTION. The coefficient of expansion of rubber is greater than of metal pipe, and sufficient allowance should be made

for this. (Coefficient of linear expansion per degree Fahrenheit, from 32 to 140°, is 0.000034.)

SUPPORTS. For normal service, place rubber pipe supports no farther apart than 1½ times the pipe diameter. When the pipe carries heated liquids, it should be supported in a trough for its entire length.

MAINTENANCE. Hard rubber, because it shows no appreciable age deterioration, requires no protective painting or other periodic refinishing. However, humid air and light cause it to discolor, and ordinary paints, lacquers, and enamels may be used to improve appearance.

RODS, TUBES, AND SHEETS

HARD-RUBBER SHEET. In sheet form, hard rubber lends itself to countless applications. Parts for electrical equipment are made from thin sheets by cutting and punching, and from larger sheets by sawing or otherwise cutting, and drilling.

Standard sheet size: 20 by 48 inches.

Thickness range: 0.008 to 8 inches and greater.

EDGES. Normally the edges are left rough but can be trimmed to definite size at the factory at slight extra cost. All untrimmed sheets are slightly thinner close to the edges.

Thickness Variations. Over areas not close to sheet edges, total thickness variations may be as great as in Table 5.

TABLE 5

Sheet Thickness, In.	*Variation, In.*
1/64	0.003
1/32	0.005
1/16	0.008
1/8	0 012
1/4	0.018
1/2	0.030
1	0.050
2	0.075
3	0.100

FINISH. Hard-rubber sheets are cured in contact with tin sheets, so a "tin finish" is standard. Sheet surfaces may be ground to a velvet finish, or may be polished to a high luster.

RODS AND TUBING. Standard length: 30 inches.

Finishes. Rough, ground, or polished. The rough finish is that exhibited after curing. The ground finish is produced by running the rod or tube through a centerless grinder. Polishing is done with felt and cloth wheels and appropriate abrasive materials.

Tubing tolerance, inside diameter: Variation will be only about half as much as outside rough-finish diameter variation.

Tubing concentricity: May vary slightly because tubing is finished on centerless grinder.

COLORS. While black is a widely used color for hard-rubber sheets, tubes, rods, and molded parts, various other solid and mottled colors can be compounded. However, the colors possible in hard rubber do not

TABLE 6. TYPICAL WEIGHTS, POUNDS (APPROXIMATE) PER SHEET 20 BY 48 INCHES

Thickness, in.	*Lb*	*Thickness, in.*	*Lb*	*Thickness, in.*	*Lb*	*Thickness, in.*	*Lb*
1/64	0 68	1/4	10.84	11/16	29.81	1 3/4	75.88
1/32	1.35	9/32	12 20	3/4	32 51	1 7/8	81.29
3/64	2.04	5/16	13.55	13/16	35.23	2	86 71
1/16	2.71	11/32	14.90	7/8	37.94	2 1/4	97 55
5/64	3.39	3/8	16.26	15/16	40.65	2 1/2	108.39
3/32	4.06	13/32	17.61	1	43.35	2 3/4	119.23
7/64	4.74	7/16	18.96	1 1/8	48.78	3	130.06
1/8	5.43	15/32	20.33	1 1/4	54.20	3 1/4	140 91
5/32	6.78	1/2	21.68	1 3/8	59 61	3 1/2	151.75
3/16	8.13	9/16	24.39	1 1/2	65 04	3 3/4	162 59
7/32	9.49	5/8	27 10	1 5/8	70 45	4	173.43

approach in brilliancy or cheapness those attainable in various plastics such as methyl methacrylate.

MATERIALS. Hard-rubber compounds may be made of crude or reclaimed rubber or various American-made rubbers. The properties listed in the preceding portion of this chapter are for hard crude rubber. When

TABLE 7. TOLERANCES, OUTSIDE DIAMETER

Diameter, in.	*Ground or polished, in.*	*Rough finish*
To 1	0.003	Approximately same as for sheet of corresponding thickness
1–2	0.005	
Over 2	0.010	
	(If required, a tolerance of ±0.0005 in. may be held)	

an American-made rubber is used, there may be slight variations. A typical Nitril compound such as Ameripol hard rubber has greater impact resistance and resistance to heat softening than ebonites of crude rubber and hard compounds of other American rubbers. Hard Nitril compounds, sometimes called Ebonars, can be machined, polished, and molded in an extensive range of shapes. They can be obtained in a

TABLE 8. TYPICAL ROD WEIGHTS, APPROXIMATE POUNDS PER LINEAL FOOT

Diam., in.	*Lb*	*Diam., in.*	*Lb*	*Diam., in.*	*Lb*	*Diam., in.*	*Lb*
1/16	0.0016	11/32	0.050	3/4	0.240	1 5/8	1.124
3/32	0.0038	3/8	0.060	13/16	0.281	1 3/4	1.304
1/8	0.0066	13/32	0.070	7/8	0.326	1 7/8	1.497
5/32	0.0104	7/16	0.082	15/16	0.374	2	1.703
3/16	0.015	15/32	0.094	1	0.426	2 1/4	2.155
7/32	0.020	1/2	0.106	1 1/8	0.539	2 1/2	2.661
1/4	0.027	9/16	0.135	1 1/4	0.665	2 3/4	3.219
9/32	0.034	5/8	0.166	1 3/8	0.805	3	3.831
5/16	0.042	11/16	0.201	1 1/2	0.958		

TABLE 9. TYPICAL TUBING WEIGHTS, APPROXIMATE POUNDS PER LINEAL FOOT

I.D., in.	*Wall, in.*															
	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	13/16	7/8	15/16	1
	Lb/ft															
1/16	013	.040	.080	.133	.200	.279	.373	.479	.599	.732	878	1 04	1 21	1 40	1 60	1 81
3/32	.017	.047	.090	.146	.216	299	.396	506	.629	.765	.915	1 08	1.25	1 44	1 65	1 86
1/8	.020	.053	.100	160	233	.319	.419	532	659	.798	.951	1.12	1 30	1.49	1 70	1 92
5/32	.023	060	110	173	250	.339	.442	.559	688	.832	988	1.16	1.34	1 54	1 75	1 97
3/16	.027	067	.120	.186	266	.359	.466	.585	.718	.865	1.02	1.20	1.38	1.58	1 80	2 02
7/32	.030	073	131	200	283	.379	.489	.612	.748	.898	1.06	1.24	1.43	1.63	1 85	2 08
1/4	.033	.080	.140	213	.299	.399	.512	.639	.778	.931	1.10	1.28	1.47	1.68	1 90	2 13
9/32	.037	087	150	226	316	.419	.536	.665	.808	.965	1.13	1 32	1.51	1.72	1 95	2 18
5/16	.040	093	.160	.240	.333	.439	.559	.692	.838	.998	1.17	1.36	1.56	1.76	2.00	2.24
11/32	.043	.100	.170	.253	.349	.459	.582	.718	.868	1.03	1.21	1.40	1.60	1 82	2 05	2 29
3/8	.047	.106	.180	.266	.366	.479	.605	745	.898	1.06	1.24	1.44	1.64	1 86	2.10	2.34
13/32	.050	113	190	.279	383	.490	.629	.772	.928	1.10	1.28	1.48	1.69	1.91	2.15	2.40
7/16	.053	.120	.200	.293	.399	.519	.652	.798	.958	1.13	1 32	1.52	1.73	1.96	2.20	2.45
15/32	.057	.126	.210	.306	.416	.539	.675	.825	.988	1.16	1.35	1.56	1.77	2.00	2 25	2 50
1/2	.060	.133	.220	.319	.432	.559	.699	.851	1.02	1.20	1.39	1.60	1.82	2.05	2 30	2 55
9/16	.067	.146	.240	.346	.466	.599	.745	.905	1.08	1.26	1.46	1.68	1.90	2.14	2.40	2 66
5/8	.073	.160	.259	.373	.499	.639	.792	.958	1.14	1.33	1.54	1.76	1.99	2 24	2 49	2 77
11/16	.080	.173	.279	.399	.532	.678	.838	1.01	1.20	1.40	1.61	1.84	2.08	2.33	2 59	2.87
3/4	.086	.186	.299	.426	.565	.718	.885	1.06	1.26	1.46	1.68	1.92	2.16	2.42	2 69	2.98
13/16	.093	200	.319	.452	.599	.758	.931	1.12	1.32	1.53	1.76	2.00	2.25	2.51	2 79	3.09
7/8	.100	.213	.339	.479	.632	.798	.978	1.17	1.38	1.60	1.83	2.08	2 34	2.61	2.89	3 19
15/16	.106	226	.359	.506	.665	.838	1.02	1.22	1.44	1 66	1 90	2.16	2 42	2 70	2.99	3.30
1	.113	.240	.379	.532	.698	.878	1.07	1.28	1 50	1.73	1 98	2 24	2.51	2.79	3.09	3.41
1 1/8	.126	.266	.419	.585	.765	.958	1.16	1.38	1 62	1 86	2 12	2 40	2.68	2.98	3 29	3.61
1 1/4	140	.293	.459	.639	.832	1.04	1.26	1.49	1.74	2.00	2.27	2.55	2.85	3.17	3.49	3.83

variety of colors. Some properties of Ebonars made from Hycar OR-15 are

Tensile strength	8,500 to 11,000 psi
Elongation	2 to 7%
Hardness, type D durometer	76 to 95
Softening temperature (ASTM D-530 method)	225 to 300°F
Impact strength (ASTM D-530 method)	75 to 130 in.-lb/in.[2]

Hard Sponge Rubber

Hard nitrogen-blown sponge is described in Chap. 20. Also, hard chemically blown sponge is made and is used for such products as croquet balls.

Buckets and Dippers

Compounded of a flexible hard rubber, buckets and dippers are designed for handling corrosive liquids. A typical 3-gallon bucket weighs about 3½ pounds empty. The wire handles can be obtained either rubber- or lead-covered or made of stainless steel. Dippers of 1-quart capacity weigh about 1 pound and of 2-quart capacity, about 1½ pounds. These hard-rubber utensils will withstand all ordinary handling and abuse without chipping or cracking. Even greater resistance to abuse is exhibited by a soft-rubber bucket (durometer 70), which can be distorted to loosen caked material.

The Working of Hard Rubber

Hard-rubber sheet, rod, tubing, and special forms are customarily converted into useful shapes by machine operations similar to those employed for wood and metal. The ease with which most hard-rubber compounds can be worked, even on automatic screw machines, is one of this material's outstanding properties. There are differences in the machinability of hard-rubber grades; and when the raw stock is being ordered, the manufacturer should be informed concerning the way it is to be worked. He then can furnish a grade having good machining properties. Because of its high sulfur content, hard rubber causes rapid wear of cutting tools and is best worked only with the very hard alloys.

Cutting. Hard rubber can be cut with a circular or band saw, power-driven knife, or thin abrasive wheel.

Circular Saws. Use a blade having teeth designed for crosscut sawing of wood. Keep the teeth sharp and set for ample clearance and file them

so they are square-faced, like teeth on a metal-slitting saw or milling cutter. For very smooth, light cuts, a planer-type blade may be used. Run the saw at about the same speed as for wood.

Band Saws. The blade should be 1/32 inch thick, 3/4 inch wide and have 5 to 8 teeth per inch. Keep it sharp and set for good clearance, and file teeth as described for circular saws. Operate the saw at a blade speed of about 5,000 feet per minute.

Power Knife. This is used for cutting thin sheet. Preheat the sheet on a steam table. After being cut, the pieces should be placed to cool on a flat surface and under weights.

Abrasive Wheels. The best method of cutting hard rubber is with an abrasive wheel of proper grit and a thickness of about 3/32 inch. The wheel should be used on a machine designed for it or on a circular saw having a suitable guard. Clamp the work so it will not twist or bind against the wheel. Speed should be about 9,500 surface feet per minute, which is equivalent to 3,000 rpm for a 12-inch-diameter wheel. The following are typical cutting-off wheels: Norton Crystolon 3/32 by 12 inches, 3736-T7-T2; Carborundum Brand Silicon Carbide Resinoid TC24-R7-B3, TC36-R7-B3, or TC54-T-B. When ordering abrasive wheels, specify the use to which they will be put.

In all cutting operations, no coolant or lubricant is necessary, although a cutting fluid might be employed with an abrasive disk if the machine is designed to handle it. Dust caused by cutting can be removed by suitable venting.

DRILLING. Use high-speed-steel twist drills with points ground to 45-degree angles (90-degree included angle). Keep the drill sharp. Special drills designed for drilling hardened steel also may prove satisfactory.

TABLE 10. RECOMMENDED SPEEDS FOR HIGH-SPEED-STEEL TWIST DRILLS

Hole Size, In.	*Rpm of Drill*
Up to 3/8	1,500
3/8–3/4	800
Over 3/4	300 or less

While holes may be drilled dry, a lubricant of plain or soda water is preferable to keep the drill cool. For maximum accuracy, drill the hole slightly undersize, then ream to finished size.

THREADING. *Tapping Holes.* Use best quality high-speed-steel taps for maximum service. Tapping may be done dry or with plain or soda water as a lubricant. Lard oil or similar threading oil is sometimes used.

Threading Rods and Tubes. Ordinary threading dies are used. The operation can be performed with hand tools or at production rates on a hand screw machine or automatic. The dies should be relieved more than for steel in order to provide a greater clearance angle.

Threading Hard-rubber Pipe. While all the threading can be done with a die, occasionally it may be desirable to cut the threads on a lathe using a single-point tool or merely to rough them in with such a tool and finish with a die. When a die is used, the routine may be as follows:

1. Warm end of pipe and insert a wood plug of a diameter that fits the pipe exactly. Let cool. (Experienced workmen often omit the plug reinforcement.)

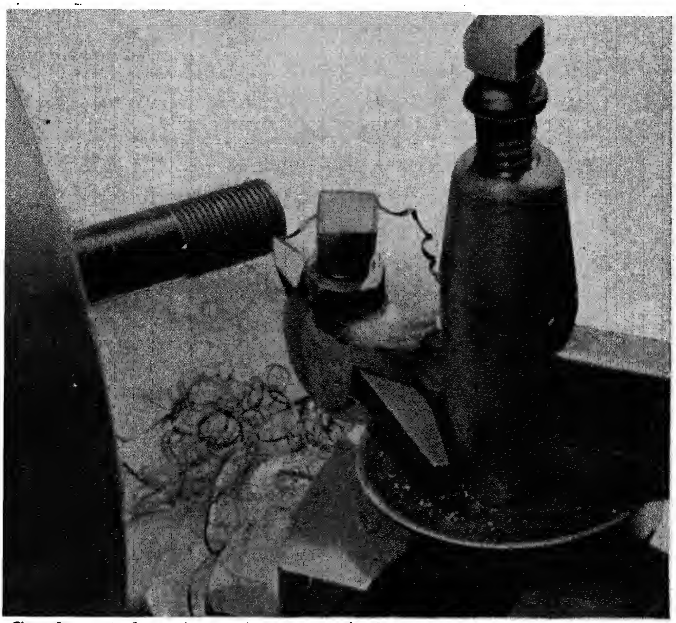


FIG. 4. Cutting 24 threads per inch on a ½-inch hard-rubber rod with a single-point lathe tool. In this case, a clean-cut thread was produced by using a tool ground with side rake and feeding it by moving the compound rest that was set at the thread angle.

2. If the pipe is oversize, true it on a lathe, taking a taper cut. Standard pipe thread taper is ¾ inch per foot.
3. Have the die sharp and provided with adequate clearance. Use plain water or soda water as a lubricant.

Most users of rubber pipe will find it best to order the threading done at the factory.

PUNCHING. Sheet hard rubber can be punched while either cold or hot, with a die that has a cutting edge (such as a steel-rule die), or with a punch-and-die combination. Thickness limit is about ⅛ inch. If the sheet has been heated to reduce the tendency to break, allowance should be made for shrinkage when cooling and the piece should be supported

to prevent warping while cooling. Shrinkage characteristics vary with compounds.

LATHE BITS AND MILLING CUTTERS. When hard rubber is machined on a lathe, the work may be done dry or with plain or soda water as a coolant. Sometimes a soap solution or oil emulsion is used. A lubricant improves the turned finish.

Cutter bit characteristics are given in the following list:

1. High-speed steel: Not recommended where accurate work is to be done in volume. Can be used for occasional, nonproduction jobs.
2. Stellite: No. 3 Red Stellite is free-cutting and otherwise satisfactory.
3. Carbide: Tools tipped with tungsten carbide have been found productive of best results, from the standpoint of both tool life between grinds and accuracy of work.
4. Diamond: A diamond-tipped tool is preferable where the closest tolerances are to be held.

Tool Grinding. A lathe tool for use in cutting hard rubber should be ground with greater end and side relief than if the same tool were to be used for steel. Doubling the relief angle recommended for steel is often satisfactory for hard rubber. More specifically, a 10- to 20-degree end relief and about 12 degrees side relief will be found satisfactory. ("Relief" and "clearance" are angles measured relative to a plane perpendicular to the tool base and, in some cases, are the same. Relief is measured at the cutting edge; clearance at the tool base.) Too little relief causes rubbing, overheating, and chattering. Also, a dull tool is likely to overheat and chatter. Top and side rakes may be zero; a negative top rake works well with some compounds, and a positive side rake can be used on high-speed-steel tools. After grinding, a little touching up with an abrasive stick or a diamond hone for carbide tips will improve the edge and lengthen time between grinds.

Milling cutters should have the same comparable angular relief as lathe tools. Use the same table feeds as for steel, and increase the spindle speeds 15 per cent over those normally used for steel. Carboloy-tipped cutters are necessary for maintaining good production and holding tolerances.

GRINDING HARD RUBBER. Sometimes it is more economical and quicker to grind a piece of hard rubber to size than to machine it. Sheet hard rubber and odd-shaped parts having flat surfaces can be finished on a Blanchard or other surface grinder.

Abrasive-coated cloth and paper are used widely for surfacing hard rubber. The coated abrasive may be in the form of a belt or glued to a drum or disk used on a conventional or special sanding machine. Sanding is done wet or dry, waterproof abrasive cloth being recommended for the

wet method, abrasive paper for dry. A jet of water directed on the abrasive cloth surface will help to keep it from loading and will improve the finish of the work.

Typical Abrasives. The following recommendations are from D. N. Rodger, of the Carborundum Company, Niagara Falls, N.Y. He explains that the gradings are not to be considered as positive for every operation and that special gradings are often required to meet varying machine conditions. Also, such variables as the operator's technique and wheel sizes and shapes must always be taken into consideration. Often it is desirable, particularly when major fabricators are involved, to consult the engineering department of an abrasive manufacturer, so the grinding problem can be submitted to an engineering study and suitable wheels or other abrasives recommended.

TABLE 11. ABRASIVES FOR RUBBER

	Dry	*Wet*
Sanding or grinding drums:		
Roughing	24-grit SIC* paper	24-grit SIC waterproof cloth
Finishing	50-grit SIC paper	50-grit SIC waterproof cloth
Sanding disks:		
Rough cutting	24-grit SIC paper	24-grit SIC waterproof cloth
Finishing	50-grit SIC paper	50-grit SIC waterproof cloth
	Abrasive wheels	
Cylindrical grinding:		
Soft rubber	Silicon Carbide Brand Resinoid C16-L-B	
Medium rubber	Silicon Carbide Brand Resinoid RC24-L6-B8	
Hard rubber	Silicon Carbide Brand Resinoid RC36-L6-B8	
Hard rubber	Silicon Carbide Brand Vitrified BC36-J4-VE	

* "SIC" = silicon carbide.

Fine grinding for better surfaces may require a grading in SIC Carborundum Brand Resinoid such as RC54-N7-B8. For centerless grinding use Silicon Carbide Brand Vitrified BC36-J4-VE.

For cylindrical grinding, roughing and finishing cuts of hard-rubber rolls, use 36 and 60 grit wheels, *e.g.*, Carborundum Resinoid 36R-12-C and 60-14-C14R, Carborundum Vitrified 365-R-W and 60-R-W.

For centerless grinding of rods and tubes, a medium-grain medium-grade wheel can be used, *e.g.*, Carborundum Vitrified 365-K-B.

POLISHING AND BUFFING. Polishing can be done with coated abrasive material while the work is revolving in a lathe, or with hand or motor-driven blocks or wheels.

First Operation. Polish with an 80-grit aluminum oxide abrasive cloth. This is free-cutting and will leave definite scratches if pressure is heavy. By easing the pressure or using dulled cloth toward the end of the operation, a finer finish is produced.

Second Operation. For a finer finish than that produced by the first operation, use an emery cloth of 1/0-grit size.

Third Operation. For a still finer finish, use emery cloth of 2/0-grit size; for maximum fineness, use aluminum oxide cloth of 320-grit size.

For removing mold blemishes from surface of hard rubber, use an 80-grit aluminum oxide or silicon carbide abrasive cloth.

Buffing. High polishes are produced on hard rubber by cloth wheels charged with progressively finer abrasive materials. The first buff is charged with an abrasive that may be a mixture of powdered pumice, beeswax, rosin, and mutton tallow or with a similar commercial preparation. Further polishing is done on a wheel charged with a commercial buffing compound in which Tripoli powder is the cutting agent. Finally, a cloth buff or wiper having no abrasive charge is used to work up the final polish.

Buffing wheels 16 inches in diameter are satisfactory for production polishing. These may be built up of felt and canton flannel varied to regulate wheel hardness; a greater proportion of felt means greater hardness. The felt and flannel are in the form of solid disks and "pie-segment" strips that can be cut from odd-shaped remnants. Disks and strips usually are alternated. In order to make provision for fluffing of the outer portion of the wheel, the felt and flannel pieces are separated by felt washers or rings serving as spacers. A washer is usually placed between every layer of felt or flannel. The wiping or finishing wheel consists of canton flannel strips and disks and felt washers and is very soft and fluffy.

FASTENING. Besides the methods of fastening already mentioned, hard rubber can be joined with the aid of many of the mechanical fasteners used for metal, wood, and various plastics. The material lends itself to the use of self-tapping screws and drive screws, which help to speed assembly in production work. Hole sizes should be such that the driving of the fasteners will not cause the hard rubber to chip or crack. Recommendations of fastener manufacturers may be followed in determining hole dimensions. No matter what the type of fastener, care should be taken not to damage the material by drawing it too tight.

Vulcalock cement can be used for making heat-cured bonds for binding hard rubber to itself and to other materials.

Storing Hard Rubber

Many consumers of hard rubber keep rods, tubes, sheet, and molded parts in storage for years, and sometimes the stock is damaged or rendered useless by improper storage conditions. All forms of hard rubber should be stored in a dark,[1] cool place, and each piece should be amply supported so that it cannot warp, sag, or otherwise become distorted. Flat sheets may be laid on level platforms made of wood or other material. Rods, tubes, and other slender sections may be kept on similar level surfaces or in troughs made of wood or metal.

Metal parts covered with hard rubber should not be subjected to sudden or extreme temperature changes because of the considerable difference between the expansion properties of the two materials. One purchaser of rubber-covered metal baskets lost a considerable portion of his stock because it was stored in an out-of-the-way shed that gave no protection from extremes of temperature; consequently, the covering cracked. In very cold weather, manufacturers will not ship metal articles coated with hard rubber except in heated cars. This is to prevent cracking of the covering as a result of extreme temperature variations.

[1] In most cases, there will be no appreciable effect on hard rubber stored where subdued daylight or light from artificial room-lighting sources strikes it. Ordinary fluorescent and similar lamps probably would be classed with incandescent lamps, but germicidal and other types whose radiation is rich in the ultraviolet region would be expected to have a greater deteriorating effect. Prolonged exposure to any kind of low-intensity light may lower surface resistivity of hard rubber. This occurs because the free sulfur on the surface is converted into sulfur trioxide. However, the original resistivity of the hard-rubber surface is easily restored by cleaning or polishing.

Chapter 12

RUBBER HOSE

Rubber hose has made it possible for engineers to accomplish such feats as the building of Shasta Dam, which some of the accompanying photographs illustrate. The chief job of hose is to carry air, water, oil, dry cement, steam, and other materials where rigid pipe is impractical or cannot go. In one respect, hose is merely a substitute for pipe; in another, it is a super pipe that possesses, among other valuable properties, flexibility, permitting it to be bent and moved easily and quickly from one place to another.

The procuring of a particular kind of hose for a particular job is largely a matter of selection, for manufacturers have developed a multiplicity of types that will meet practically any requirements. And when there is no hose adequate for a job, a manufacturer usually is willing to develop one. The design engineer interested in obtaining a hose for a specialized purpose will do well to follow the procedure recommended for so many other rubber products. That is, he should consult the hose manufacturer early in the development of the product or application; tell him what he wants the hose to do and under what conditions of pressure, temperature, etc., it will be used; and then let the hosemaker draw upon his vast experience in selecting the hose materials, method of manufacture, and other details.

However, there are some general details about rubber hose that the prospective user will find interesting and usually helpful to know.

Structure and Materials. The simplest kind of "hose" is merely a tube whose walls are homogeneous. Such tubes are made of various compounds of crude and American rubber, of polyvinyl chloride, and of various other flexible plastics. They are formed by extruding the material through a suitable die; and for this reason, extruders are known around a rubber factory as "tube machines."

By merely braiding or weaving cords or threads into a tube or sewing strips of cotton duck into tubular form, another simple type of hose is produced. Although not wholly impermeable to water, such hose made of linen is sometimes used for emergency fire fighting. And because water under pressure will ooze through fabric hose, lengths having one end

closed and the other fitted with a garden hose coupling are used as "oozer hose" for soaking the soil of lawns and gardens.

When these two simple forms of hose—the plain rubber tube and the plain fabric tube—are combined and sometimes reinforced by metal, we have the makings of an endless assortment of modern rubber-hose types. In a typical industrial hose, the inside tube is a simple extruded part. This is covered by one or several reinforcing layers of woven fabric or by cords braided like the streamers around a Maypole. Then over the reinforcing plies is placed the cover, a rubber compound designed to resist wear and rough handling. The tube, reinforcing layers, and cover are vulcanized into a single structure. By varying the nature and thickness of the rubber compounds and the nature or number of reinforcing plies and perhaps by adding further elements such as wire coiled around the inside or outside of the hose or braided or woven into reinforcing layers, hosemakers create products for specific types of service.

MANDREL-CURED CONSTRUCTION. This type of hose is usually available only in lengths up to 50 feet. Tubular steel mandrels are covered by an extruded tube. Next the reinforcement is applied, either in the form of rubber-impregnated fabric (cotton duck) or braids of cotton, steel wire, asbestos, rayon, or other fibers to form as many plies as are desired. Finally, the cover material is applied. Then a temporary wrapping of finely woven fabric is added. The lengths are cured in a steam vulcanizer, after which the temporary wrapping is removed and the hose stripped from the mandrel with the aid of compressed air forced between the mandrel and the tube.

Advantages usually claimed for mandrel-cured hose are

1. Uniform inside diameter.
2. Smoother inner surface, which results in minimum pressure loss.
3. When made with a braided reinforcement, the resistance of a firm mandrel permits braiding under high tension, thereby increasing capacity of the hose to resist internal pressures. The firm mandrel also permits a closer control of braiding angles, which results in an improved uniformity of pressure resistance.

LONG-LENGTH CURE CONSTRUCTION. Instead of being supported on 50-foot steel mandrels, the hose tube is inflated with compressed air and moved, usually vertically, through a braiding machine. In some cases, the reinforcement is of woven fabric wrapped spirally around the tube in a continuous process. Lengths up to 500 feet are then passed through a lead press in which semimolten lead is formed as a temporary jacket around the hose. The lead-jacketed hose is wound on large reels, then passed into a closed steam vulcanizer for cure. Curing heat is supplied by the steam surrounding the hose and by hot water pumped under

pressure through the tube of the hose. After curing, the lead is removed in an automatic stripping machine.

Advantages of long-length cure construction include:

1. Lower cost than other methods—thus providing the user with more hose value for medium- and low-pressure services.

2. Because of the long lengths available, the weight, inconvenience, and cost of coupling are reduced.

3. Because it has a molded surface (either smooth or corrugated), the lead press cure hose is of better appearance than mandrel-cured hose that has a surface showing an impression of the temporary cloth wrapping used during vulcanization.

The disadvantages of the long-length cure include the following:

1. Greater tolerance in inside diameter is required. For services involving the handling of liquids, compressed air, and other gases at normal pressures, this is no handicap.

2. The reinforcement must be applied at lower tensions than is the case with mandrel-cured hose, and angles of braiding cannot be controlled so closely. As a result, long-length hose usually cannot be recommended for the highest pressures. Developments in the art, however, have resulted in long-length hose, for spray solutions and other liquids, which is capable of withstanding a working pressure of 800 psi, in sizes up to ¾ inch inside diameter.

3. The long-length construction is usually limited to hose having a maximum of 2 inches outside diameter; consequently, it is not available for inside diameters in excess of 1½ inches.

Wrapped Construction versus Braided Construction. There is some difference of opinion concerning the relative advantages and disadvantages of braided and wrapped constructions. Wrapped hose has been made for over 100 years, whereas braided hose was introduced about 55 years later. The braided-hose process has been gradually improved during this time, but many users became prejudiced against it because of imperfections in its earlier stages of development. Not only has the method of vertical braiding been highly improved; but by braiding and curing on mandrels, braided hose today is equal to or has surpassed the wrapped-fabric type of hose in almost all kinds of service.

Advantages claimed for wrapped fabric hose include

1. Greater resistance to bending near the couplings—at which points some failures take place.

2. Better adaptability to processing when very soft, pure rubber compounds are used—as in the case of acid hose and sandblast hose.

3. Has proved better than braided hose for handling steam, because the method of building does not permit trapping of small air pockets.

Advantages claimed for braided hose include

1. More effective resistance to injury from kinking than wrapped fabric hose.
2. More flexibility.
3. Seamless plies which are more uniform in construction.

It was formerly observed that wrapped-fabric air drill hose resisted external blows more effectively than braided hose. In this respect, how-

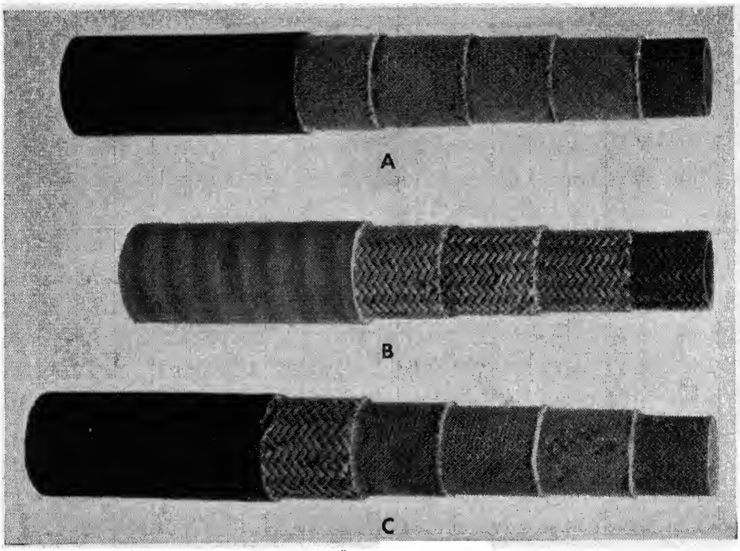


FIG. 1. This photograph shows three different types of rubber-hose construction. (*A*) Wrapped-construction hose. Rubber-inpregnated, woven-cotton duck weighing from 5 to 32 ounces per square yard is wrapped around the tube in several layers to form a spiral in cross section, each layer being termed a "ply." (*B*) Braided-construction hose. The hose is reinforced by strands of yarn or wire braided over the tube in the same way that ribbons are braided around a Maypole. Superior flexibility and resistance to kinking are characteristics of braided-construction hose. (*C*) Combination-construction hose. The reinforcement shown consists of three plies of wrapped duck, over which is braided a ply of yarn. This combines the internal strength and rigidity of fabric with the flexibility and kink resistance of braided strands.

ever, wrapped hose has no advantage over the more improved types of braided hose. It was a common belief that the cover of wrapped hose offered greater abrasion resistance, but this is not the case because covers can be compounded to provide maximum abrasion resistance no matter what type of reinforcement is used. When internal pressure is applied to wrapped hose, it twists and contracts in length; when internal pressure is applied to braided hose, it does not twist. Mandrel braided hose will remain practically constant in length under internal pressure, while long-length braided hose will contract slightly.

Woven Hose. In woven hose the reinforcement consists of cord or yarn—of cotton, rayon, or other fibers—and, in some cases, of strands of wire alternating with cotton strands. The "filler" strands are carried by shuttles traveling in a circular path continuously throughout the length of the hose. The "warp" strands run lengthwise. The burst re-

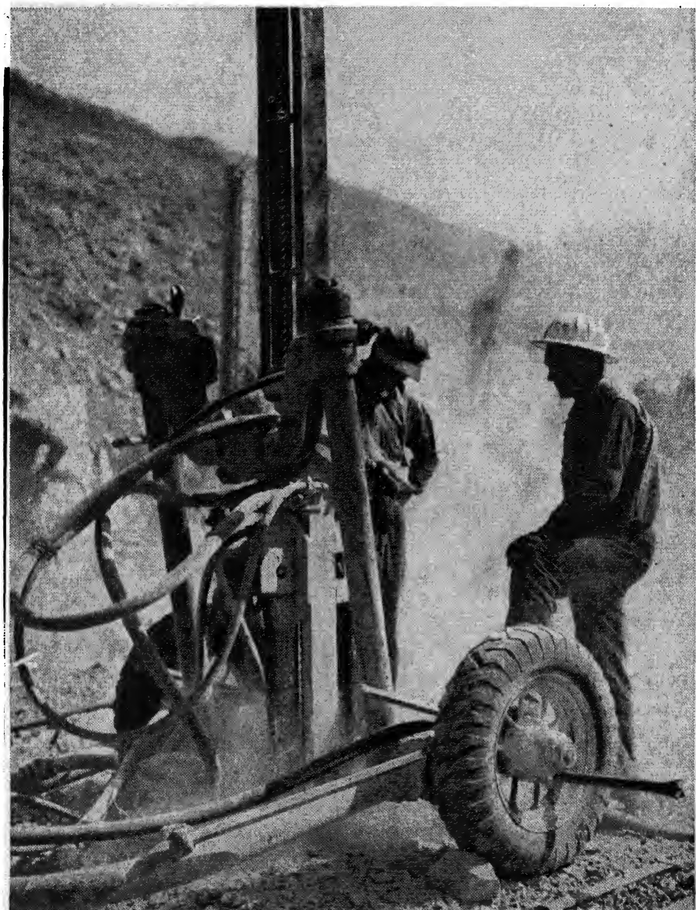


Fig. 2. An Ingersoll wagon drill in operation during the construction of Shasta Dam. The large hose is a 1-inch three-braid air hose; smaller one is ½-inch three-braid air hose. (*Photograph from U.S. Bureau of Reclamation.*)

sistance of the hose depends mainly on the filler strands, which are reinforced and protected by the interwoven warp strands.

There are two general types of woven hose:

1. *Cotton Rubber-lined Hose.* This construction affords high burst resistance per pound of hose weight and is the standard construction for

2. *Chernack-loom Hose.* The reinforcement consists of a combination of wire and yarn. It is used extensively for services handling liquids either under pressure or suction, such as gasoline and oil tank wagon hose and water suction hose. It is also adaptable to lightweight hose in the larger diameters for such requirements as rock-wool blowing.

When internal pressure is applied, woven hose tends to. twist and elongate. In municipal fire hose, this twist is minimized by using two jackets woven in opposite directions.

Kinds of Hose

Hundreds of different kinds of rubber hose have been made, but it is possible to list only a few on these pages. The more important industrial types will be mentioned, together with some of the principal characteristics of each. The engineer who desires to use hose in a special application may, upon consulting the manufacturer, discover that there is in existence a type of hose that will meet his requirements fully. When a new type hose must be developed, it should be kept in mind that hose manufacturers usually specify minimum quantities they can economically supply. Thus, one hose manufacturer will not supply less than 25,000 feet of special-run, nonstock, single-braid hose ½ inch in diameter and has similar limitations on other special types and sizes.

Air Hose

Hose for carrying compressed air must withstand some of the most severe service conditions encountered by any kind of hose. The tube must be able to withstand the heat developed by the "Diesel action" in compressing air. The practice of lubricating air tools by oil conveyed through the air hose makes it necessary to compound the tube so it will withstand oil. The rubber must not flake or crumble, for it then would cause tool clogging. The air-hose carcass must withstand high expanding pressures. The hose carcass must be made so it will not be abnormally damaged by being dragged over sharp stones, run over by trucks, or immersed in oil, water, or acid solutions or by being exposed to all kinds of weather or otherwise subjected to rough handling.

Typical Constructions. *Braided and Molded.* Tube compounded for air service, two or three plies of braided cord embedded in rubber, smooth or corrugated rubber cover.

Wrapped Duck, Mandrel-cured. Tube compounded for air service, four to seven plies of cotton duck, rubber cover.

TYPICAL AIR-HOSE DATA. The following figures are representative of the characteristics built into industrial air hose. They are not intended to represent the maximum limits of working pressure, etc.

Air Temperatures. The temperatures normally reached by air as it leaves a compressor range up to 250°F.

TABLE 1. AIR-HOSE DATA

Size and Construction	*Wt., lb/ 100 ft*	*Length, max., ft*	*O.D., in.*	*Working pressure, psi*
Superior quality braided:				
¼ in. 2-braid	15	500	⅝	250
⅜ in. 2-braid	22	500	25/32	200
½ in. 2-braid	29	500	31/32	200
½ in. 3-braid	36	500	1 1/16	250
¾ in. 2-braid	46	500	1 9/32	150
¾ in. 3-braid	55	500	1 ⅜	200
1 in. 3-braid	66	500	1 ⅝	150
1¼ in. 3-braid	80	300	1 ⅞	125
1½ in. 3-braid	96	300	2 ⅛	125
Standard quality braided:				
½ in. 2-braid	25	500	29/32	125
½ in. 3-braid	31	500	1	200
¾ in. 2-braid	40	500	1 7/32	125
¾ in. 3-braid	48	500	1 5/16	175
High quality wrapped:				
½ in. 4-ply	37	50	1 3/32	300
¾ in. 4-ply	51	50	1 ⅜	275
1 in. 5-ply	70	50	1 11/16	250
1¼ in. 5-ply	82	50	1 15/16	250
1½ in. 6-ply	111	50	2 ¼	250
2 in. 6-ply	150	50	2 13/16	200
Wrapped, for connecting pipe line and manifold:				
2 in. 6-ply	159	50	2 13/16	175
2½ in. 7-ply	212	50	2 13/32	175
3 in. 8-ply	267	50	3 31/32	175
4 in. 7-ply	351	50	5 ⅛	175

Kinking. If an air hose has a tendency to kink badly, it may be old or poorly constructed or its tube may be weakened by oil and heat action. Although it generally is desirable to prevent air-hose kinking, some users make a practice of bending the hose sharply in order to shut off the air.

PRESSURE LOSSES. As air travels through a hose, friction between it and the tube walls cause a drop in pressure. The drop is proportional to hose length but is greater in smaller diameter hose than in larger diameter because friction is greater in the smaller hose. Friction loss varies directly

with velocity of the air. Table 2 shows the pressure drop for various lengths of hose.

TABLE 2. FRICTION LOSS IN PSI PER 50 FT OF COUPLED AIR HOSE

Flow, free air, cu ft/min	*Hose I.D., ½ in.*			*Hose I.D., ⅝ in.*			*Hose I.D., ¾ in.*		
	Gas pressure, lb			*Gas pressure, lb*			*Gas pressure, lb*		
	20	*40*	*60*	*20*	*40*	*60*	*20*	*40*	*60*
2	0.22	0.14	0.10	0.06	0.04	0.03	0.02	0.01	
4	0.89	0.73	0.41	0.24	0.15	0.11	0.09	0.07	0.04
10	5.26	3.03	2.59	1.42	0.95	0.69	0.49	0.34	0.24
20	....	14.00	10.34	6.05	3.79	2.72	2.10	1.37	0 96
30	....	.....	.....	....	8.48	6.05	4.70	3.09	2.11
50	....	.....	.....	....	....	....	....	8.60	6.04

Flow, free air, cu ft/min	*Hose I.D., 1 in.*			*Hose I.D., 1¼ in.*			*Hose I.D., 1½ in.*			*Hose I.D., 2 in.*		
	Gas pressure, lb			*Gas pressure, lb*			*Gas pressure, lb*			*Gas pressure, lb*		
	20	*40*	*60*	*20*	*40*	*60*	*20*	*40*	*60*	*20*	*40*	*60*
20	0 4	0.25	0.18	0.11								
30	0.9	0.5	0.4	0.25	0.16	0.11						
50	2.5	1.04	1.14	0 7	0.43	0.31	0.24	0.18	0.11			
100	9.3	6.16	4.54	2.56	1.7	1.25	0.90	0.73	0.44	0.18	0.12	0.09
200	...	....	....	....	6.85	5.0	3.8	2.9	1.75	0.74	0.47	0.35
300	. .	....	...	..	15.3	11.0	8.5	6.5	3.8	1.18	1.05	0.75
400	.	. .	...	...	.. ..	.	...	....	...	3.0	1.88	1 38

Friction loss is directly proportional to length of hose and for flow volumes other than shown, calculate the friction loss as proportional to the squares of the volumes.

For air-operated small hand tools the following information on air consumption may be of some value in determining the proper size hose for economical use and operation:

For 8 cu ft/min or less, use	¼ in. I.D. hose
8 to 11 cu ft/min	5⁄16 in. I.D. hose
11 to 15 cu ft/min	⅜ in. I.D. hose
15 to 40 cu ft/min.	½ in. I.D. hose

Where more than 150 ft of hose is used, it is advisable in most cases to use the next larger size of hose.

Acid Hose

This type is designed for handling acids in industrial plants. Wrapped fabric construction, in 50-foot maximum lengths, is common. The hose will handle most inorganic salts, alkalies, and acids other than nitric, chromic, and concentrated sulfuric. Acid discharge hose has a wall of sufficient flexibility to permit use of pinch cocks for controlling flow. Acid suction hose has a reinforcement of wire that permits use up to full vacuum without collapsing.

Table 3. Acid-hose Data

Size (I.D.), in.	*O.D., in.*	*Wt., lb/ft*
Acid suction hose:		
1½	2 9/16	180
2	3 ⅛	250
2½	3 ⅝	300
3	4 3/16	365
Acid discharge hose:		
¾	1 7/16	59
1	1 11/16	72
1¼	1 15/16	85
1½	2 3/16	97
2	2 11/16	123
2½	3 3/16	150
3	3 11/16	180

Couplings. These may be rubber-to-rubber (Goodrich Flexseal) joints; glass, hard rubber, or acid-resisting alloy nipples plus regular hose clamps; or rubber-covered flanged steel nipples. Uncapped acid hose should be placed on nipples with the aid of a liberal amount of rubber coupling cement in order to protect exposed fabric.

Beverage Hose

This type of hose, also known as brewer's hose, must have two properties in addition to the usual ones: (1) It must impart no odor or taste to the wine, beer, or other beverage. (2) It must be nontoxic. Although crude-rubber compounds have been used for making brewer's hose for more than a half century, tasteless American-rubber compositions have been developed. Such a compound may itself have a distinguishing odor, yet impart no taste or odor to the beverage. The inner tubes of beverage hose are usually white; the outer coverings black or white.

TABLE 4. BEVERAGE-HOSE DATA

Brewer's or wine size, in. (I.D.)	*Plies*	*Wt., lb/ft*	*O.D., in.*	*Working pressure, psi*
3/4	4	54	1 11/32	175
1	4	66	1 19/32	150
1 1/4	4	78	1 27/32	125
1 1/2	4	110	2 3/16	125
2	5	188	2 7/8	125

Besides being suitable for beer, wines, and similar liquids, beverage hose can be used for carrying hot or cold fruit juices, or vinegar; for filling cans in ice plants; and for vacuum service, *e.g.*, up to a vacuum of 23 inches. Beverage hose is usually labeled for the particular service for which it was originally intended, thus: "Wine," "Brewer's," "Vinegar." Tubing made of plasticized polyvinyl chloride or similar plastics is suit-

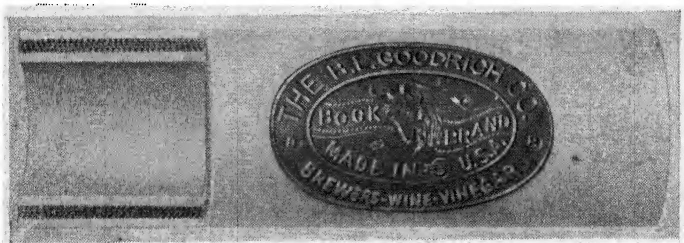


FIG. 3. Brewer's hose of typical construction.

able for beverage service. Such tubing can be made translucent, so the flow of the liquid can be observed.

VINEGAR HOSE. This is designed specially for carrying hot or cold vinegar, cider, and apple pomace. It replaces the wood and copper pipes formerly used. A hose having a thick tube that resists acetic acid penetration should be selected in preference to light vinegar or acid hose some-

TABLE 5. VINEGAR-HOSE DATA

Size (I.D.), in.	*Plies*	*Wt, lb/100 ft*	*O.D., in.*	*Working pressure, psi*
3/4	4	49	1 5/16	175
1	4	60	1 9/16	150
1 1/4	5	72	1 13/16	125
1 1/2	4	90	2 3/32	125
2	5	126	2 21/32	125

times used. The covering of such hose should withstand sun, rain, frost, snow, and extremes of temperature.

Blowing Hose

This hose is used principally for blowing rock wool or other insulating material into the walls of buildings. It is suitable also for blowing or suction operations in handling grain, collecting dust, etc. It is usually made in 50-foot lengths on a mandrel and therefore has a smooth tube offering minimum resistance to movement of material. The hose is light and flexible and can be obtained with either a smooth outside surface or shallow corrugations.

Table 6. Blowing-hose Data

Size (I.D.), in.	*Wt, lb/100 ft*	*O.D., in.*	*Max. discharge pressure, psi*
2	65– 68	$2^{13}/_{32}$	30–50
$2\frac{1}{2}$	79– 82	$2^{29}/_{32}$	30–50
3	110–125	$3\ ^{7}/_{16}$	30–50

Butane-propane Hose

This is designed for handling bottled, liquefied petroleum gas of the type used where natural gas is not available. It is compounded to withstand the petroleum products handled and to resist vapor pressures and temperatures normally encountered. Typical sizes (inside diameter) range from ½ to 3 inches., and the working pressures up to 350 pounds.

Cement-handling Hose

This type is used for transferring dry cement at high velocity.

Typical Construction. It has a smooth tube, ⅛ inch thick, made of abrasion-resisting rubber. Over the tube are wrapped-fabric plies and a spiral wire reinforcement, and finally a rubber cover.

This hose can be used for the handling of other dry materials. Its sizes range normally from 4 to 8 inches, and weights from about 3 to 7¼ pounds per foot.

Cement-gun Hose

This hose is designed for use with equipment that places concrete in molds and other places by blowing. The dry cement is mixed with other

ingredients at the gun nozzle. The hose has high abrasion resistance in the tube. The outer ply of fabric forms the cover.

Chemical Hose (For Chemical Fire Extinguishers)

The somewhat misleading term "chemical hose" is applied to hose used on chemical or "booster" type fire-protection equipment employed by municipalities and in factories, and *not* to hose used in chemical plants or laboratories.

Chemical hose may be of either braided or wrapped construction. Some typical properties are given in Table 7.

Table 7. Chemical-hose Data

Size (I.D.), in.	*O.D., in.*	*Ply or braid*	*Wt., lb/100 ft*	*Working pressure, psi*
3/4	1 9/32	4 ply	46.5	150
1	1 17/32	4 ply	59.1	125
1 1/4	1 27/32	5 ply	79.5	125
1 1/2	2 3/32	5 ply	91.6	100
3/4	1 9/32	3 braid	47	175
1	1 9/16	3 braid	66.7	150
1 1/4	1 13/16	3 braid	73.2	150

The following lengths are normally supplied: wrapped plies, 50 feet; braided, longer.

Creamery Hose

Creamery or dairy hose is designed for service under difficult conditions encountered in the processing or manufacture of milk, cream, ice cream, and other dairy products; sugar production; all kinds of canning; bakeries; and plants making pickles, oleomargarine, vinegar, cider, and numerous other food products.

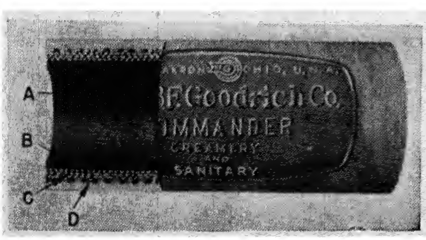


Fig. 4. The four component parts of typical creamery hose. (*A*) High-quality steam-hose tube. (*B*) Wrapped plies of strong duck. (*C*) Braided ply of strong cords. (*D*) White cover of special quality and thickness.

In a typical creamery hose, the tube is the same type as that used in steam hose and is resistant to hot water and steam. Over the tube are placed three or four plies of wrapped duck or a combination of duck and a ply of braided cord. The

outer cover is resistant to fatty acids, fish and other animal oils, various cleaning compounds, and abrasion. The cover may be black, gray, or white. Hose lengths are provided with rubber-capped ends to protect

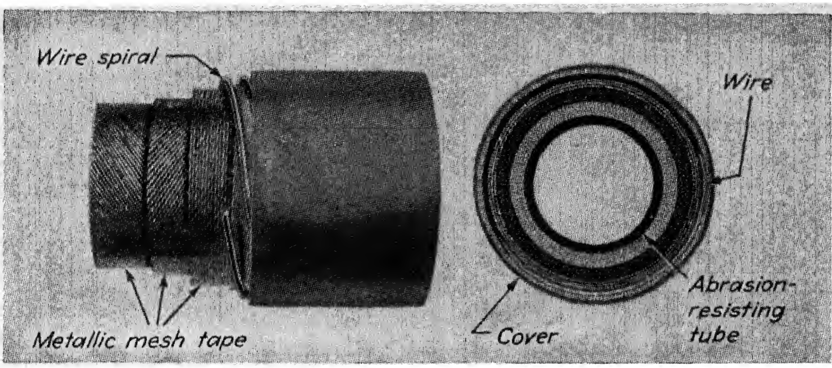


FIG. 5. Rotary driller's hose has a complex structure. Two crossed plies of metallic mesh tape control pressure, while a third closely wound ply increases strength against burst. This hose withstands 5,000 psi test pressure.

plies, and lengths may be ordered with built-on, soft, rubber-and-fabric nozzles that will not damage porcelain or other equipment.

Creamery hose is made in such sizes as ½, 1¼, and 1½ inches, in addition to those given in Table 8.

TABLE 8. CREAMERY-HOSE DATA

Size (I.D.), in.	*O.D., in.*	*Ply*	*Braid*	*Wt., lb/100 ft*	*Working pressure, psi*
¾	1⅜	4	1	50	175
1	1⅝	4	1	62	150

SOFT-RUBBER NOZZLES

Hose size, in.	*Nozzle length, in.*	*Outlet diameter, in.*
¾ or 1	12	⅜

DISTILLATE HOSE

For a discussion of this type, see Oil Hose, page 266.

Driller's Hose

Since it is used for rotary drilling of oil wells, the hose must withstand pressures required to circulate to the bottoms of deep wells the mud or slush used to lubricate the drill bit, remove cuttings, and seal off the forces of suddenly tapped gas pockets. Normal working pressure is 1,000 psi or less, but a sudden stoppage may create a water hammer action that boosts pressure to several times the working figure.

Table 9. Driller's Hose Data

Size (I.D.), in.	*Body O.D., in.*	*Fabric plies**	*Metal plies†*	*Wt., lb/ft*	*Delivery test pressure, psi*
2	2 15/16	5 by 7	Outer wire winding	3.8	800‡
2 1/2	3 1/2	8 by 10	Outer wire winding	5.4	800‡
2 1/2	4 1/4	8	2, metallic mesh tape	6.4	3,000
2 1/2	4 3/4	8	2, metallic mesh tape; 1, solid round wire	9.6	4,000
2 1/2	5	9	3, metallic mesh tape; 1, solid round wire	13	5,000
3	4 3/4	8	2, metallic mesh tape	7.3	2,000
3	5 1/4	8	2, metallic mesh tape; 1, solid round wire	10.9	4,000
3	5 1/2	9	3, metallic mesh tape; 1, solid round wire	14.6	5,000

* Second figures show plies at hose ends.

† In addition to body metal reinforcement, ends are reinforced. The first two items in table (wire-wound hose) have two extra duck plies at ends. All the others have an additional ply of metallic mesh tape extending back 4 feet from each end.

‡ Suitable for shallow-well drilling at working pressures up to 500 psi.

Driller's hose usually is strengthened by crossed helical windings of metallic mesh tape.

Typical Construction. 1. Tough, strong tube designed to resist abrasion. Nine plies of duck. Two plies of metallic mesh tape placed at crossed angles to control pressure. One ply of metallic mesh tape closely

wound to increase burst resistance. Layer of fabric over which is a spiral ply of solid round wire to resist kinking and crushing. Cover made of rubber compounded to resist rough handling, abrasion, etc. Tube may be made oil resisting.

2. Tube $\frac{3}{16}$ inch thick compounded for strength, toughness, and oil resistance. Eight plies of special duck. Two plies of cross-braided steel wire of high tensile strength. Two more duck plies. Cover compounded to resist abrasion, etc.

Rotary driller's hose is furnished in lengths up to 55 feet.

Fire Hose

Fire hose is designed specially to meet the requirements of various classes of service such as municipal fire fighting and mill and plant protection.

Industrial fire hose, or "mill hose," is a term used to describe a hose designed primarily for fire protection in factories and plants.

Hose Tube. It is made of rubber compounded to provide flexibility and long life.

Jacket. One or more layers of woven cotton cord protect the tube from damage and wear, resist pressure stresses, and hold the tube to uniform diameter. The warp cords, running lengthwise, are placed so they take the wear and resist the longitudinal pressure stresses, while the filler cords, spiraling around the tube, resist circumferential stresses.

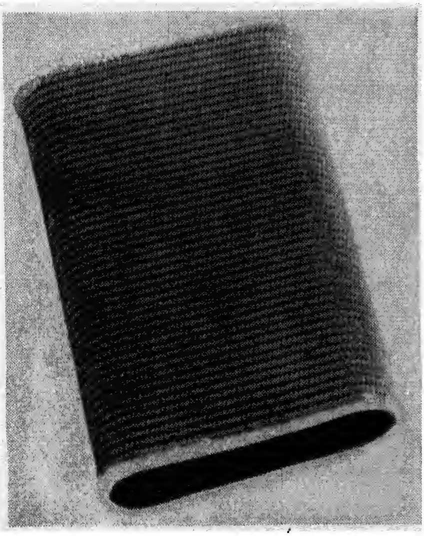


Fig. 6. Fire hose of single-jacket construction.

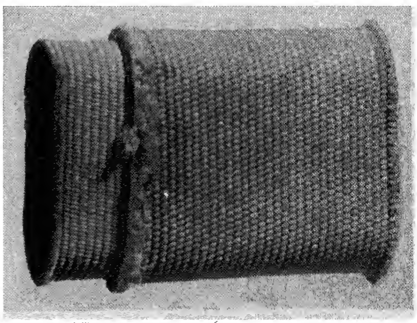


Fig. 7. Fire hose of double-jacket construction.

Flat Cure. Fire hose spends most of its life resting in a coiled or folded position. When it is cured in a round cross section like other hose,

portions of the tube are under considerable strain when the hose is reeled or folded on a rack. When the tube is cured in a flattened position, the hose can be racked or coiled without placing the rubber under tension. Since rubber deteriorates more rapidly when subjected to tension, the

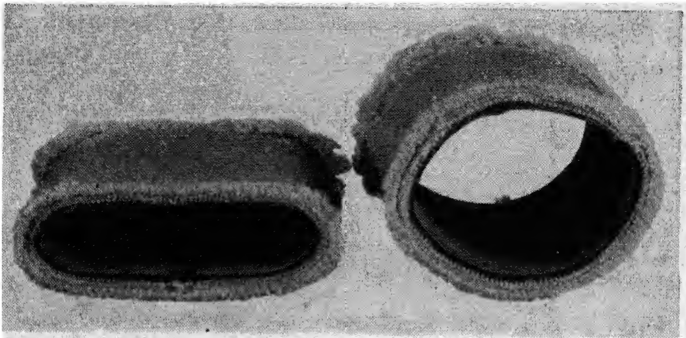


FIG. 8. Flat-cured fire hose (*left*) can be reeled or folded without subjecting the rubber to excessive stress. (*Right*) Ordinary fire hose.

flat cured hose will have a useful life perhaps 50 per cent longer than a similar round cured one. Under water pressure, a flat cured hose expands to the normal round shape, with no impairment of efficiency.

END PROTECTION. A network of hard-twisted cords built into the

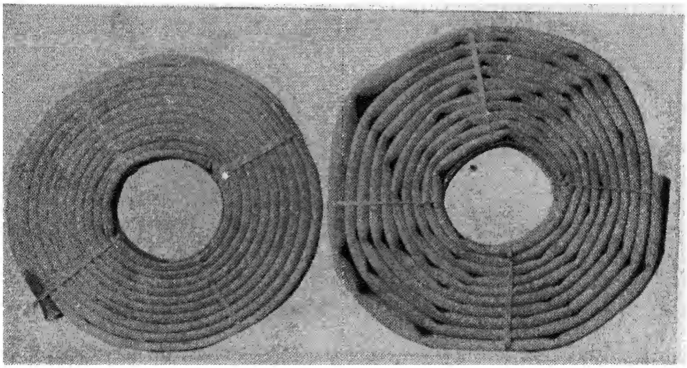


FIG. 9. Comparative folding action of flat-cured fire hose (*left*) and ordinary round-section fire hose (*right*).

hose cover for a distance of approximately 12 inches back from the coupling reduces hose damage in the vicinity of the coupling.

JACKET TREATMENT. Formerly, various waxes were universally used to render hose coverings resistant to mildew and other damage. Now, various improved treatments render the jackets water- and mildew-resistant without affecting the adhesion between cover and tube. These

prevent the hose from becoming excessively heavy through water logging and maintain hose flexibility in cold weather.

RUBBER-COVERED FIRE HOSE. Such hose is of the same basic construction as that having a fabric jacket, but a rubber cover is added to provide protection against acid, oil, wear, and other agents. The rubber cover increases weight per foot, a hose having a single cotton jacket and a rubber cover weighing about the same as a conventional fire hose having two cotton jackets.

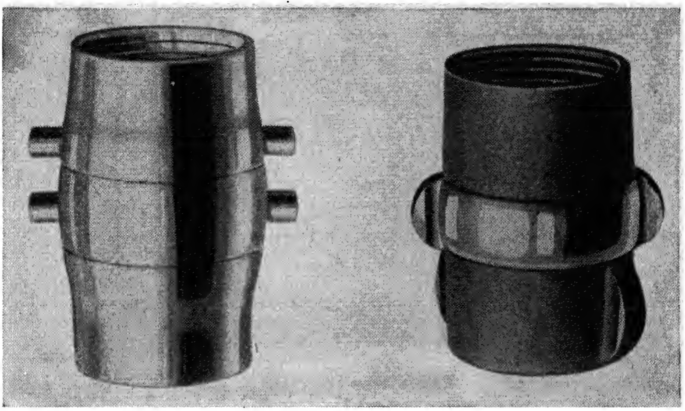


FIG. 10. Pin-lug fire-hose coupling (*left*); rocker-lug type (*right*). The pin is the most popular for industrial fire hose, while the rocker lug is preferred when several lengths of coupled hose are used together and subjected to pulling and tugging.

FIRE-HOSE GASKETS. Although rubber gaskets have been used widely, gaskets made of plasticized polyvinyl chloride, *e.g.*, Koroseal, produce a tight joint without the use of spanner wrenches, prevent swivel "freezing," retain their shape, and last indefinitely.

TABLE 10. KOROSEAL-GASKET SIZES

Thickness, in.	*I.D., in.*	*O.D., in.*
5/32	1½	2
3/16	2 9/16	3 5/16

TYPICAL FIRE-HOSE CHARACTERISTICS. *Twist and Elongation.* In a fire hose, low twist and elongation are indicative of good performance under service conditions.

Length. Average length of fire hose under 10 psi internal water pressure is 50 feet, measured from back to back of couplings. Because of

temporary jacket shrinkage as a result of coiling and humidity change, new hose not under pressure may be as much as 18 inches short, but this shrinkage disappears when hose is subjected to working pressure.

TABLE 11. FIRE-HOSE DATA

Size, (O.D.), in.	*Wt., lb/50 ft*		*Jackets*	*Initial test pressure, psi*	*I.D. of coupling tailpiece, in.*
	Uncoupled	*Coupled*			
		Municipal fire hose			
1½	20	23	1	300	1 7/8
1½	22.1	25	1	350	1 7/8
1½	30.5	33.5	2	400	2
1½	27.5	30.5	2	400	2
2½	35	41	1	300	2 15/16
2½	39	45	1	350	2 15/16
2½	53	59.5	2	400	3 3/32
2½	56.5	63	2	400	3 3/32
		Industrial fire hose			
1	13	14.6	1	200–250	1 5/16
1¼	16.5–19	18–23.6	1	200–300	1 11/16
1½	19–22	20.6–23.6	1	200–300	1 7/8
2	26–30	28.2–32.2	1	200–300	2 3/8
2½	33–38	37.3–42.3	1	200–300	2 15/16
1½	28.8–32.5	30.5–35.5	2	250–400	2
2	37.3–41	40–44.6	2	250–400	2 1/2
2½	46–56.5	52.5–63.2	2	250–400	3 1/16
3	73	83	2	250–400	3 21/32

UNLINED HOSE. Woven from linen and having no rubber in its construction, unlined hose is intended for emergency fire protection inside buildings. Sizes include ¾, 1, 1½, 2, and 2½ inches. It can be made in continuous lengths and withstands test pressure of 300 pounds. After each use, such hose must be dried thoroughly.

CARE OF FIRE HOSE. Tests at 1½ to 2 times working pressure should be made at least once a year. Hose kept on rack should be reracked once a month in order to eliminate the tendency of rubber to crack at transverse bends. In an average factory, four or five spare lengths should be kept on hand so tests can be made without reducing the number of units available for an emergency.

Drying. The hose should be dried by suspending it from a tower or on an inclined rack or in any other manner that permits water to run

out without wetting adjacent hose or equipment, and the cotton to dry in freely circulating air.

GASOLINE HOSE

GASOLINE-PUMP HOSE. *Typical Construction.* This hose has a smooth American-rubber (Nitril) tube that is not affected by gasoline or oil and does not affect gasoline color. Two or three plies of braided cord form the reinforcement. The rubber cover is compounded to resist oil, sunlight, and

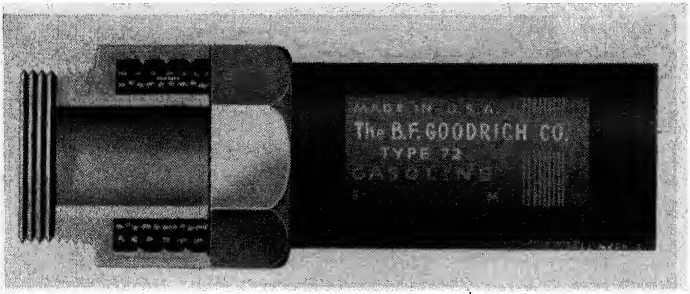


FIG. 11. Gasoline-pump hose showing a coupling attached by expanding a bronze sleeve into the hose wall. Internal ridges of the coupling grip the hose cover.

abrasion. A flexible spiral winding of braided or stranded wire between two of the fabric plies extends the full length of the hose, to ground static electricity. In order to eliminate leakage, gasoline hose should be attached to the pump with the aid of a thread lubricant that does not dissolve in gasoline.

TABLE 12. GASOLINE-PUMP-HOSE DATA

Size (I.D.), in.	*O.D., in.*	*Wt. lb/100 ft*
¾	1¼	46
1	1½	62

GASOLINE TANK-CAR AND TRUCK HOSE. This is used for loading and unloading tank cars at refineries, bulk stations, and service stations. It also will handle kerosene, distillate, Diesel oil, and other fuel oil and is suitable where the liquid remains in the hose line with the flow controlled at the nozzle.

Typical Construction. This hose has a mandrel-cured oilproof American-rubber tube, three plies of braided cotton yarn, and a braided or stranded wire built into it for static grounding to couplings. Its American-rubber cover is designed to resist moisture, sunlight, oils, and solvents.

TABLE 13. TANK-CAR- AND TRUCK-HOSE DATA

Size (I.D.), in.	*O.D., in.*	*Wt., lb/100 ft*
1½	2⅙	85
2	2$\frac{9}{16}$	111
2½	3$\frac{5}{32}$	155
3	3¾	198

SEMIFLEXIBLE OR "HARD" GASOLINE HOSE. This type is excellent for use on trucks with carrying tubes and can be employed in suction service. If crushed, it can be made round again by pounding.

Construction. It has an oil- and gasoline-proof American-rubber tube, and a circular woven reinforcement with circular wire filler, the wire acting also as a static conductor. Its cover is compounded of oil-, sunlight-, abrasion-, and moisture-resisting American-made rubber.

TABLE 14. SEMIFLEXIBLE TANK-CAR- AND TRUCK-HOSE DATA

Size (I.D.), in.	*O.D., in.*	*Wt., lb/100 ft*
1½	2 $\frac{1}{16}$	119
2	2 ⅝	153
2½	3 $\frac{1}{16}$	176
3	3$\frac{21}{32}$	208

OIL-HANDLING HOSE

In addition to gasoline hose that will handle oils, there are various types of hose made for specific jobs in handling crude petroleum, fuel oil, gasoline, etc.

FIG. 12. Fuel-oil hose made of rubber compounded to resist the action of oil.

OIL SUCTION AND DISCHARGE HOSE. This is used for carrying oil and gasoline between sea lines and tankers, on oil tankers and barges, at refineries and distributing terminals, etc.

Smooth-bore Dock-loading Hose. Typical Construction. The tube is made of oilproof rubber compound. Over this are several layers of frictioned fabric, next a spirally wound round steel wire embedded in a rubber

cushion, and then additional fabric plies. The cover resists sunlight, abrasion, and weather.

Rough-bore Dock-loading Hose. A heavy, flat, spirally wound steel wire is flush with inner surface of tube in order to prevent crushing and flattening in suction service and act as static conductor. Between wire and tube is a layer of impregnated fabric. The tube is oilproof rubber. Next are several plies of fabric, then a winding of round wire, a layer of fabric, and a cover consisting of a layer of oil-, sun-, and abrasion-resisting rubber which may be protected by a spiral duck winding.

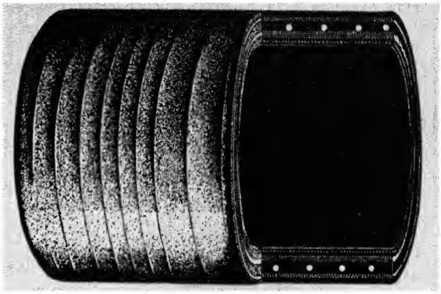


FIG. 13. Dock-loading hose designed for handling oil or gasoline in suction or discharge. A round steel-wire spiral reinforces the wall. The tube is of American-made rubber.

In some dock-loading hose, the steel bore wire is replaced by an aluminum wire for better corrosion resistance, and additional duck plies are used.

Sea-loading Hose. This is designed to remain on the sea bottom for long periods and to resist barnacle attack. It is similar to rough-bore dock-loading hose described but has a third flat-wire winding whose outer surface is flush with cover.

TABLE 14*a*. OIL-HANDLING-HOSE DATA

Size, (I.D.), in.	*O.D., in.*	*Plies**	*Wt., lb/ft, no fittings*	*Type*
4	5 5/8	6 by 8	7.8	Smooth-bore dock-loading
6	7 7/8	7 by 9	15.03	Smooth-bore dock-loading
8	10	8 by 10	20	Smooth-bore dock-loading
10	12 1/8	9 by 11	25.98	Smooth-bore dock-loading
3	4 15/32	6 by 8	5	Rough-bore dock-loading
4	5 1/2	7 by 9	8.2	Rough-bore dock-loading
6	7 9/16	8 by 10	17	Rough-bore dock-loading
8	9 3/4	9 by 11	24	Rough-bore dock-loading
10	11 13/16	10 by 12	33.6	Rough-bore dock-loading
6	7 5/8	7 by 9	19.7	Sea-loading hose
8	9 3/4	8 by 10	30.3	Sea-loading hose
10	12	11 by 13	39.8	Sea-loading hose
3	4 1/16	4	3.6	Smooth-bore barge-loading
4	5 1/8	5	5.25	Smooth-bore barge-loading
6	7 1/4	6	9	Smooth-bore barge-loading
3	4 1/8	4	4.48	Rough-bore barge-loading
4	5 1/4	5	6.4	Rough-bore barge-loading
6	7 1/2	8	10.7	Rough-bore barge-loading

* Second figure shows number of plies at hose ends.

Barge-loading Hose. This is of lighter construction than dock-loading hose and is made in both smooth- and rough-bore types.

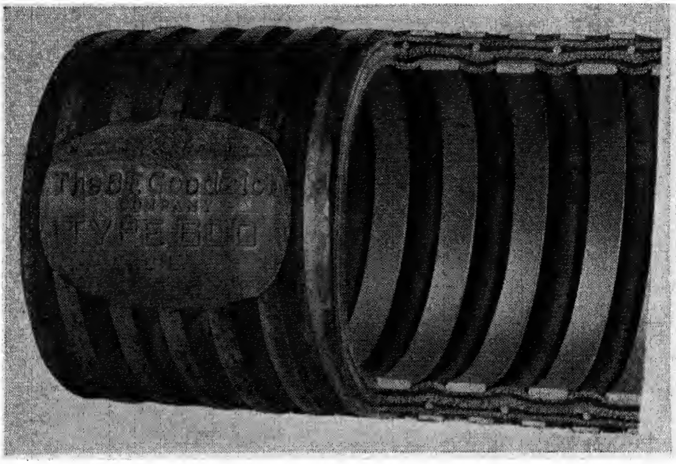


Fig. 14. A heavily reinforced sea-loading hose made to withstand rough handling in offshore loading of liquid cargo and designed to rest on the sea bottom.

Other types of hose designed specially for the oil industry and similar service include oil and kerosene truck delivery, airplane refueling, turbine or still-cleaning hose, and distillate hose.

Hydraulic-control and Greasing Hose

This type of hose is used for pressure greasing of machinery and vehicles; as oil hose on dump truck, grader, scraper, bulldozer, and snow-

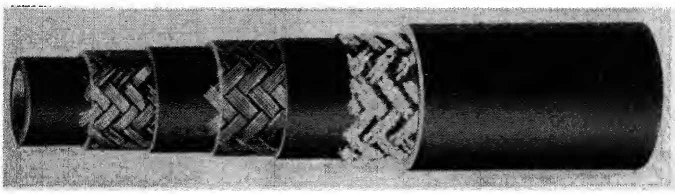


Fig. 15. Hydraulic-control hose showing typical construction. (*A*) The tube is resistant to grease, oil, gasoline, etc. (*B*) and (*D*) Seamless braids of fine steel wire placed with exactness of position and angle. (*C*) and (*E*) Elastic rubber plies that bond braids and add flexibility. (*F*) Seamless ply of braided cotton cords tieing hose cover to carcass. (*G*) Cover of tough rubber that resists oil, sunlight, and flexing, and that withstands abrasive wear better than steel. This figure may serve to identify the various parts of a typical rubber-hose structure, with the exception of spiral wire reinforcements such as those visible in Figs. 14, 23, and 24.

plow hydraulic rams; as oil hose on riveting machines, die-sinking equipment, preforming presses, vises, feed cylinders, and other machine-tool

applications; for carrying gases at pressures up to 150 atmospheres; as oil lines in automatic lubrication systems on machine tools, bottling equipment, etc.; and for handling mud on portable oil-well-drilling rigs.

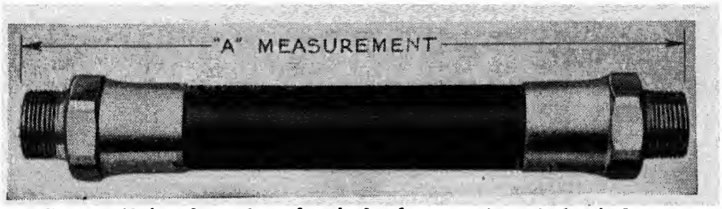


FIG. 16. In specifying hose lengths, it is the practice of the industry to use the over-all length measured from extremities of couplings, as indicated by the "A" Measurement in this figure. Portions of lengths occupied by couplings are taken into consideration when cutting the hose.

HIGH-PRESSURE HYDRAULIC-CONTROL HOSE. *Typical Construction.* The tube is of oil- and grease-resisting American rubber. Over this are usually two (sometimes one or three) plies of seamless braided fine steel wire, with a ply of elastic rubber between each wire ply. (A 1-foot length

TABLE 15. HIGH-PRESSURE HYDRAULIC-CONTROL-HOSE DATA

Commonly used sizes

Size (I.D.), in.	*No. wire braids*	*O.D., in.*	*Wt., lb/100 ft uncpld.*	*Recommended working pressure, psi*
1/4	2	11/16	31	7,000
3/8	2	7/8	51	5,000
1/2	2	1	58	4,000
3/4	2	1 5/16	83	3,000
1	2	1 9/16	109	2,000
1 1/4	3	2	164	2,000
1 1/2	3	2 1/4	194	2,000
Special sizes				
3/16	1	1/2	13	4,000
1/4	1	5/8	20	4,000
3/8	1	49/64	31	3,000
1/2	1	31/32	38	2,500

of hose may contain 1/5 mile of wire.) Over the outermost wire ply is another ply of soft rubber, and then a ply of braided cotton cords to tie the cover to the carcass. The rubber cover is compounded to resist sunlight, flexing, abrasion, and oil.

Measuring Lengths. Hydraulic-control hose is normally measured over-all, to include all of the couplings.

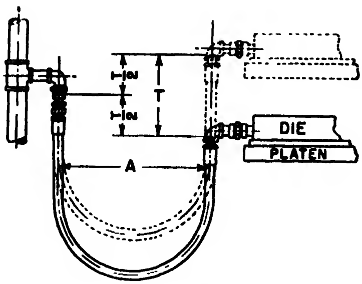


Fig. 17*a*.

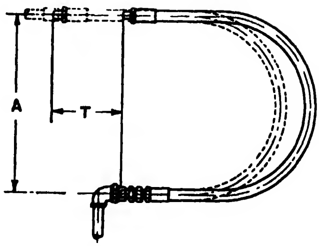


Fig. 17*b*.

Fig. 17*a* and *b*. Method of figuring correct bending radii for various sizes of hydraulic-control hose.

I.D. of hose, in.	*B constant for straight portion including coupling*	*Min. A, in.*	*Min. over-all length, in.*	
			Fig. 17*a*	*Fig.* 17*b*
¼	10	8	23 + ½*T*	23 + *T*
⅜	10	10	26 + ½*T*	26 + *T*
½	12	14	34 + ½*T*	34 + *T*
¾	14	19	44 + ½*T*	44 + *T*
1	16	22	51 + ½*T*	51 + *T*
1¼	18	26	59 + ½*T*	59 + *T*
1½	20	30	67 + ½*T*	67 + *T*

T Designates the amount of travel, while *A* represents the smallest diameter to which hydraulic hose should be bent. Should larger bending diameters be used, apply the following formulas:

Over-all length $= B + 1.57A + \frac{1}{2}T$, when conditions are as in Fig. 17*a*.

Over-all length $= B + 1.57A + T$, when conditions are as in Fig. 17*b*.

B is a factor which includes the length of the couplings and allows for straight sections of hydraulic hose beyond each fitting. These straight sections act as neutral zones to prevent bending strain from localizing directly back of the couplings.

Bending Radii. To avoid premature failure, hydraulic-control hose subjected to repeated bending in service should be of correct length, as indicated in Figs. 17*a* and *b*.

Low-pressure Hydraulic-control Hose. This is used for carrying return fluid from hydraulic rams to pump. Typical construction has an American-made rubber tube, reinforcing plies of braided cotton yarn, and a cover of oil- and abrasion-resisting rubber.

TABLE 16. LOW-PRESSURE HYDRAULIC-CONTROL-HOSE DATA

Size (I.D.), in.	*No. cotton braids*	*O.D., in.*	*Wt., lb/100 ft uncpld.*	*Max. working pressure, psi*
1/4	1	17/32	11	200
3/8	2	11/16	16	200
1/2	2	7/8	28	150
3/4	2	1 1/4	46	125
1	2	1 1/2	62	125
1 1/4	3	1 13/16	80	125
1 1/2	*	2 1/16	110	100

* Reinforcement consists of woven cotton with noncollapsing, helical wire filler.

OXYACETYLENE AND OXYHYDROGEN WELDING HOSE

Lightness, flexibility, safety, and toughness are qualities required for welding service. Welding hose can be used for carrying air, as on small compressors, paint-spray equipment, etc.

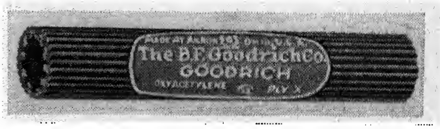


FIG. 18. Oxyacetylene hose used by welders. The tube is of nonblooming rubber compound designed to withstand hot gas. Hose for carrying acetylene or hydrogen has a red cover, while that intended for carrying oxygen or air has a black or green cover.

TYPICAL CONSTRUCTION. The smooth, nonblooming tube is compounded to resist oxidation and deterioration from hot gas. Long-length braided construction is used. The cover is made of tough rubber and corrugated to increase wear resistance.

DOUBLE WELDING HOSE. This consists of parallel lengths of hose, each of appropriate color, joined together by a rubber web. However, many welders prefer to use single hose lengths and bind them together with friction or adhesive tape applied at intervals.

TABLE 17. DISTINGUISHING OXYGEN HOSE FROM ACETYLENE AND HYDROGEN HOSE

Gas	*Hose cover color*	*Fitting thread**	*Fitting markings*
Acetylene or hydrogen (inflammable gas)	Red	Left-hand	Notched on hexagon surface
Oxygen or air	Black or green	Right-hand	Smooth hexagon swivel

* A common size of swivel nut is 9/16 inch by 18 thread.

TABLE 18. WELDING-HOSE DATA

Size, (I.D.), in.	*O.D., in.*	*Wt., lb/100 ft*	*Working pressure, psi**
3/16	13/32	6.45	200
1/4	19/32	13.45	225
5/16	21/32	15.6	225
3/8	23/32	17.7	200

* Welding hose normally is made to withstand a bursting pressure 5 or more times the recommended working pressure. Also, such hose is built to resist kinking and damage caused by sharp bending.

SANDBLAST HOSE

This hose is used for carrying sand or other sharp, abrasive materials at high velocity for cleaning metal surfaces, smoothing castings, etching glass, engraving tombstones, and similar work. The useful life of the hose is the time required to wear through the tube, which is extra thick, *e.g.*, 1/4 inch, and compounded to resist abrasion. To produce tube smoothness, the hose is vulcanized on polished mandrels.

FIG. 19. The tube in sandblast hose is thick and compounded to withstand the action of fast-moving abrasive particles.

TYPICAL CONSTRUCTION. The extra thick tube is compounded to resist abrasion and to conduct static electricity, and is cured on polished mandrels for bore smoothness. Surrounding the tube are four plies of heavy duck. The cover is the same stock as the tube.

TABLE 19. SANDBLAST-HOSE DATA (4-PLY HOSE)

Size (I.D.), in.	*O.D., in.*	*Wt., lb/50 ft*	*Working pressure, psi*
3/4	1 11/32	31	150
1	1 27/32	46	150
1 1/4	2 3/32	54	125
1 1/2	2 11/32	62	100
2	2 27/32	78	75
2 1/2	3 3/8	98	75
3	3 7/8	114	75

Lengths. Standard factory length is 50 feet. When cutting lengths for use, it is desirable to provide more hose than actually needed. Most of the tube wear occurs at the intake coupling; and after the tube is worn through there, a short portion of the hose can be cut off and the remainder recoupled. Also when the hose is bent continually at one point, it should be turned or rotated frequently to expose less worn tube portions to the strongest force of the sand stream. Short-radius bends should be avoided.

Sand, Cement Discharge Hose

This is used for sand discharge and cement placement work. The tube is made extra thick and resistant to abrasion. Over the tube are fabric plies reinforced with wire. The cover is compounded for toughness and abrasion resistance.

Table 20. Sand- and Cement-discharge-hose Data

Size (I.D.), in.	*O.D., in.*	*Tube thickness, in.*	*Plies*	*Wt., lb/ft*
2½	3²⁷⁄₃₂	¼	4	3.2
3	4¹¹⁄₃₂	¼	4	3.7
4	5¹¹⁄₃₂	¼	4	4 7
5	6¹¹⁄₁₆	½	5	8.2
6	7¹³⁄₁₆	½	5	10.3
8	9 ⅞	½	6	13.3
10	12¹¹⁄₃₂	½	8	18 9
12	14 ½	½	10	24

Cement Grout or "Mud" Hose

Its construction is similar to that of sand and cement discharge hose, except that additional fabric plies are used. This hose is designed to withstand high pressures such as 500 to 1000 psi.

Table 21. Mud-hose Data

Size (I.D.), in.	*O.D., in.*	*Tube thickness, in.*	*Plies*	*Wt., lb/ft*
2	3³⁄₁₆	³⁄₁₆	6	2.9

While the 2-inch size is standard, other sizes are made. Grout hose is used to carry concrete under pressure in connection with tunnel and shaft work, building dams, etc.

Spray Hose (Paint)

While welder's hose can be used for carrying air in some kinds of paint spraying, hose specifically compounded to resist solvents is required for

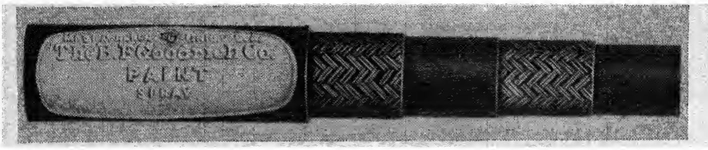


Fig. 20. Typical construction of paint-spray hose. Its tube withstands lacquers, synthetic enamels, and other chemicals that would destroy ordinary rubber compounds.

lacquers and synthetic enamels. Welder's hose should not be used for fluids.

Table 22. Spray-hose Data

Size (I.D.), in.	*O.D., in.*	*Braid plies*	*Wt. lb/100 ft*	*Max. working pressure, psi*
1/4	1/2	1	9.4	150
5/16	39/64	1	14.4	150
3/8	11/16	1	17.3	150
3/8	11/16	2	17.2	200
1/2	7/8	2	23.8	150

Table 23. Paint-spray Air-line-hose Data

Size (I.D.), in.	*No. of braids*	*O.D., in.*	*Wt., lb/100 ft*	*Max. working pressures, psi*
1/4	2	5/8	15	250
3/8	2	25/32	22	200
1/2	2	31/32	29	200
3/4	2	1 9/32	46	150
	Plies			
1/4	3	1/2	8	150
5/16	3	9/16	9	150
3/8	3	21/32	12	125
Braided cover				
1/8		17/64	1.8	200
3/16		21/64	2.5	200
1/4		25/64	3.3	150
5/16		29/64	4.0	125

Typical Construction. This hose has a smooth tube made of a material that resists powerful paint solvents. One or two cotton plies form the reinforcement. The cover is of dense American rubber that resists sunlight, solvents, and aging.

Paint-spray Air-line Hose. This is designed to carry air to paint-spray guns, especially heavy and outside-work types.

Typical Construction. The tube is made of oilproof rubber, and reinforcing plies are of braided cotton. The cover is of tough rubber compound.

Braided-cover Air Hose. This is designed for lighter guns. Its cover is cotton braid applied either by braiding over cured tube or by vulcanizing it to tube.

Steam Hose

This is used for all varieties of steam handling including the operation of steam hammers, pile drivers, pumps, and other severe service. Steam hose must be designed to withstand both heat and high pressures. The lowest temperature at which steam can be generated at sea level is 212°F. When steam is under pressure, the temperature increases. The handling of superheated steam requires a hose that will withstand great heat.

In steam-hose design involving fabric reinforcement, the chief problem is to keep the heat from destroying the fabric. This is accomplished by such means as the use of a rubber tube of low thermal conductivity and surrounding the fabric with similar rubber insulation. Most failures of fabric steam hose result either from external damage or from gradual weakening of the cotton carcass. Steam hose that has reinforcements made of wire or asbestos instead of cotton offers much greater resistance to heat damage.

Some typical steam-hose constructions are described briefly below:

All-wire Reinforced. The tube is heat resisting and retains elasticity longer than ordinary rubbers. Next to the tube is a multiple-end high-tensile-steel wire tape braided at an angle that permits only enough expansion to make coupling insertion feasible. The wire is braided with interstices, so the tube unites with the next insulating layer of heat-resisting rubber. Over this layer is a second ply of braided wire when hose inside diameter exceeds 1 inch. When the hose diameter is 1 inch or less, an asbestos braid is imbedded in the rubber layer outside the single wire reinforcement; in sizes from 1¼ inch upward, a ply of woven asbestos fabric is used instead of the braid. Finally, on smaller sizes, there is a thick, tough cover compounded to resist aging.

This hose is designed for saturated steam to 200 psi (388°F) and superheated steam to 390°.

TABLE 24. BURST-PROOF STEAM-HOSE DATA

Size (I.D.), in.	*O.D., in.*	*Tolerance in O.D., in.*	*Approx. net wt, lb/100 ft*†	*Correct sizes of boss clamps, in.*
½	1 5/32	±3/64	56.4	5/8
¾	1 7/16	±3/64	72.1	¾
1	1 23/32	±1/16	110.0	1
1¼	2 1/16*	±1/16	202.2	1¼
1½	2 5/16*	±1/16	226.6	1½
2	2 13/16*	±1/16	280 6	2
2½	3 5/16*	±3/32	339 3	2⅛

* The O.D. of the hose under the wire winding.
† Outside wire winding included on sizes 1¼ and over.

HOSE FOR SATURATED STEAM TO 150 PSI (366°F). Special heat-resisting rubber is reinforced by wrapped fabric plies. This hose is suitable for superheated steam to 366°F. Its maximum length is 50 feet.

TABLE 25. STEAM-HOSE DATA (TO 150 PSI)

Size (I.D.), in.	*O.D., in.*	*Plies*	*Wt., lb/50 ft*
¾	1 9/16	6	34
1	1 15/16	7	49
1¼	2 7/32	7	62
1½	2 9/16	8	78
2	3 1/16	8	96
2½	3 ¾	10	136

HOSE FOR SATURATED STEAM TO 100 PSI (338°F). This is suitable for superheated steam to 338°F. It is reinforced by wrapped fabric plies, and its maximum length is 50 feet.

TABLE 26. STEAM-HOSE DATA (TO 100 PSI)

Size (I.D.), in.	*O.D., in.*	*Plies*	*Wt., lb/50 ft*
½	1 15/64	5	25
¾	1 31/64	5	33
1	1 27/32	6	45
1¼	2 ⅛	6	58
1½	2 ⅜	6	66
2	3 1/32	8	100

Hose for Saturated Steam to 40 Psi (287°F.). This hose is for general low-pressure steam and hot-water handling. It is reinforced by wrapped fabric plies, and its maximum length is 50 feet.

TABLE 27. STEAM-HOSE DATA (TO 40 PSI)

Size (I.D.), in.	*O.D., in.*	*Plies*	*Wt., lb/50 ft*
½	1	4	17
¾	1 5/16	5	25
1	1 9/16	5	31

Wire Winding. Sometimes a wire winding is used over a steam hose to enable it to withstand sharp bending and frequent flexing, to resist expansion, and to prevent kinking.

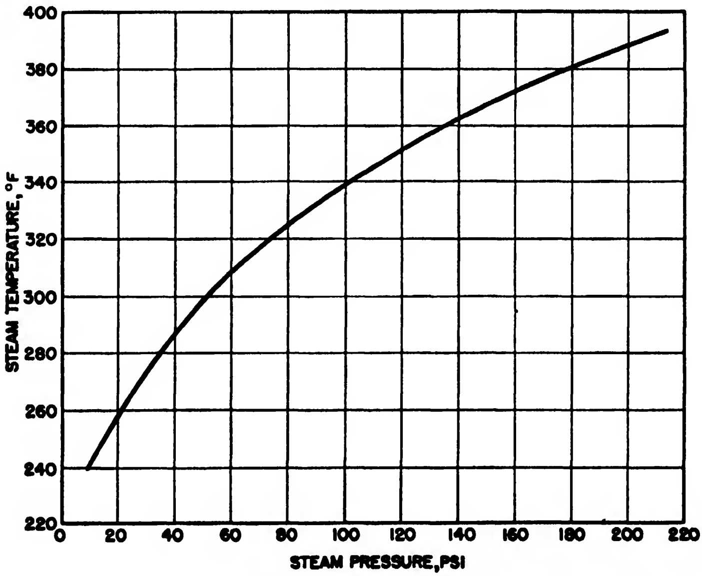


FIG. 21. Relations between steam temperature in degrees Fahrenheit and steam pressure in pounds per square inch.

Shutoff. Steam systems usually are designed so valves are at the input ends of hose in order to enable the hose to "rest" when not in use. The outlet end of the hose should remain open. If it is closed, the steam remaining in the hose will condense, and the resulting vacuum may damage the hose structure.

Water Suction Hose

This is used for sand dredging work, removing water from excavations, and similar jobs. Suction hose is built so it is reasonably light in weight and flexible yet has walls that withstand the collapsing action developed by powerful pumps and the crushing action of accidental forces.

Wire-reinforced Suction Hose. The customary way of reinforcing the hose carcass for suction service is to incorporate a spirally wound steel wire either in the carcass or inside the bore. When the wire is in the bore, the hose is known as rough bore; the fabric covering the wire spiral is pulled down so it partly fills the spaces between the turns, thus increasing bore smoothness. Flat, hardened, and tempered steel wire of rectangular, oval, or half-round cross section, galvanized to protect it from corrosion, is commonly used.

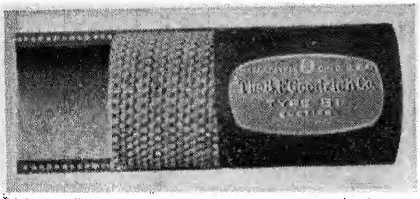


Fig. 22. Smooth-bore suction hose having a reinforcement that was circular-woven on a Chernack loom. The spiral-wire insertion is held in place by woven cords.

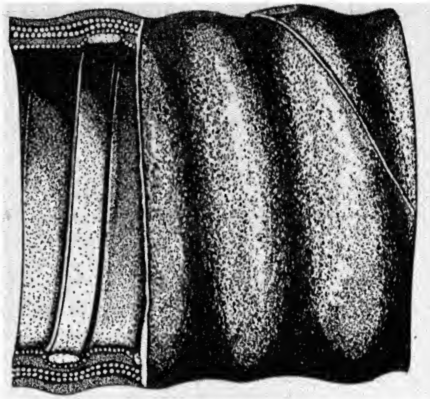


Fig. 23. A general-utility, rough-bore suction hose used widely by contractors. The flat-wire spiral stiffens the hose and reduces tube wear.

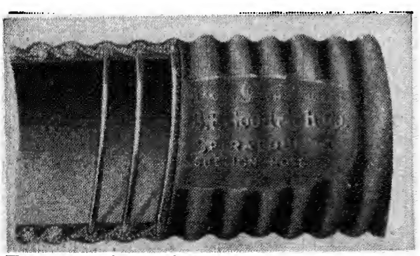


Fig. 24. Smooth-bore suction hose having the "Spiralock" construction in which fabric is locked around a spiral-wire insertion. If crushed, this hose can be pounded back into shape without seriously damaging it.

Smooth-bore suction hose has a reinforcing wire of round cross section embedded in the carcass between the tube and cover. For light suction service and in small sizes, "hard-rubber" hose having no metal reinforcement is available.

While the selection of a rough- or a smooth-bore wire-reinforced hose seems to be largely a matter of personal opinion (the two types are used

interchangeably for a great many services), some of the characteristics claimed for each type may be summarized:

TABLE 28. WIRE-REINFORCED SUCTION HOSE

Rough Bore	*Smooth Bore*
Handles any noncorroding water	Suitable for water containing corrosive chemicals
Can be used for water containing solids of low abrasive properties	Will handle water containing highly abrasive solids
If crushed, difficult or impossible to restore to shape	If crushed, can be pounded back into shape without damaging carcass
Can be used as discharge hose up to about 25 psi	Can be used as discharge hose up to about 50 psi

At one time, rough-bore hose was lower in cost than smooth-bore, but this is no longer true. Since smooth-bore hose can now be made with the tube so thoroughly united to the carcass that it will not collapse in a high vacuum, rough-bore suction hose is rapidly declining in popularity.

REPRESENTATIVE TYPES OF SUCTION HOSE. *Excavating and General-utility Service.* The B. F. Goodrich Spiralock hose is of novel construction. A spiral of round steel wire is covered with frictioned fabric in such a way that a portion of the fabric is wrapped around the wire, securely anchoring the coils in position. This assembly is placed over a smooth rubber tube on a mandrel. The abrasion-resistant rubber cover is applied over the fabric-covered wire, and the whole vulcanized into a unit. The hose is strong, light, and highly flexible.

TABLE 29. EXCAVATING- AND GENERAL-UTILITY HOSE

Size (I.D.), in.	*Over-all O.D., ends, in.*	*Wt., lb/ft*	
$1\frac{1}{2}$	$2\frac{1}{16}$	0.73	Length of blank ends is 3 in. in all sizes
2	$2\frac{9}{16}$	0.93	
$2\frac{1}{2}$	$3\frac{1}{16}$	1.12	
3	$3\frac{9}{16}$	1.53	Maximum length, 50 ft
$3\frac{1}{2}$	$4\frac{1}{8}$	1.80	
4	$4\frac{5}{8}$	2.20	

General Service (Contractor's, Trench, etc.). Although considerable rough-bore hose is employed by contractors, smooth-bore is usually preferred.

Sand and Gravel Suction. The tube of tough rubber compound is $\frac{1}{4}$ or $\frac{1}{2}$ inch thick. Next there is a network of cord to ensure good adhesion to the tube. Surrounding this is a spirally wound spring-steel wire $\frac{5}{16}$ inch in diameter imbedded in resilient rubber, and then several plies of extra

TABLE 30. GENERAL-SERVICE HOSE

Size (I.D.), in.	*O.D., in.*	*Wt., lb/ft*
1½	2 1/16	0.8
2	2 5/8	1.2
2½	3 9/64	2.0
3	3 45/64	2.8
4	4 31/32	3.4
5	6 13/32	5.7
6	7 13/32	6.7

heavy duck united by friction rubber. In the extra heavy construction, a second spiral of round wire is incorporated into this fabric section. The hose cover is of tough rubber 1/16 inch thick.

TABLE 31. SAND AND GRAVEL SUCTION-HOSE* DATA

Size (I.D.), in.	*O.D., in.*	*Wt., lb/ft*
Standard construction, 1-wire reinforcement, ¼-in. tube		
4	5 21/32	7
6	7 25/32	14
8	10	21
10	12 1/8	27
12	14 1/8	33
14	16 3/16	38
16	18 5/16	47
18	20 5/16	52
Extra heavy construction, 2-wire reinforcement, 3/8-in. tube		
12	14½	32
14	16½	37
16	18 5/8	44
18	20 5/8	55

* Made to order in any length from 3 to 50 feet, with enlarged ends.

Light-service Suction Hose without Wire Reinforcement. The tube is of smooth, abrasion-resistant compound. Six wrapped plies of frictioned fabric are used. This hose is cured to a semihard rubber and is often called a "hard-rubber suction" type.

Vacuum Hose. This type is used for industrial air suction and vacuum cleaning. Its typical construction is as follows: The tube is surrounded by

TABLE 32. TYPICAL LIGHT-SERVICE SUCTION HOSE

Size (I.D.), in.	*O.D., in.*	*Wt., lb/ft*
1	$1\frac{1}{2}$	0.6
$1\frac{1}{4}$	$1\frac{13}{16}$	0.9
$1\frac{1}{2}$	$2\frac{1}{16}$	1

a spiral wire reinforcement and fabric reinforcing plies. The rubber cover is compounded to resist dragging over floors, etc. Sizes usually range from $\frac{3}{4}$ to $2\frac{1}{2}$ inches. Vacuum hose for domestic service is essentially the same, except that it is light in construction and has a fabric cover.

FIG. 25. High-duty water hose.

WATER HOSE

This type of hose is made in various grades ranging from ordinary garden hose up to special types designed for handling high pressures in road building and other construction work; in greenhouses, mines, sugar mills; etc.

TYPICAL CONSTRUCTION. The smooth tube is of rubber compounded to withstand hot or cold water. It has braided-cotton reinforcing plies, and its cover is compounded to withstand severe handling and abrasion.

TABLE 33. TYPICAL WATER HOSE

Size (I.D.), in.	*O.D., in.*	*Braids*	*Wt., lb/100 ft*	*Working psi*	*Max. length, ft*
$\frac{1}{2}$	$\frac{31}{32}$	2	28	200	500
$\frac{3}{4}$	$1\frac{1}{4}$	2	42	200	500
1	$1\frac{1}{2}$	2	55	200	500
$1\frac{1}{4}$	$1\frac{7}{8}$	3	83	200	300
$1\frac{1}{2}$	$2\frac{1}{8}$	3	98	200	300
2	$2\frac{23}{32}$	4 plies	133	150	
$2\frac{1}{2}$	$3\frac{9}{32}$	5 plies	185	150	

JETTING HOSE. This is a special hose designed for hydraulic sluicing, stripping, bank grading, and high-pressure air and water service in pile-driver work.

It is not possible to list all the types of hose made, but the foregoing details concerning hose size, construction, and applications provide a general picture of the developments that have been made in the hose industry. In most cases where a new hose is to be ordered, the service obtained from the hose it is to replace can be used as a guide in making a selection. When the hose is for a new installation or when the hose

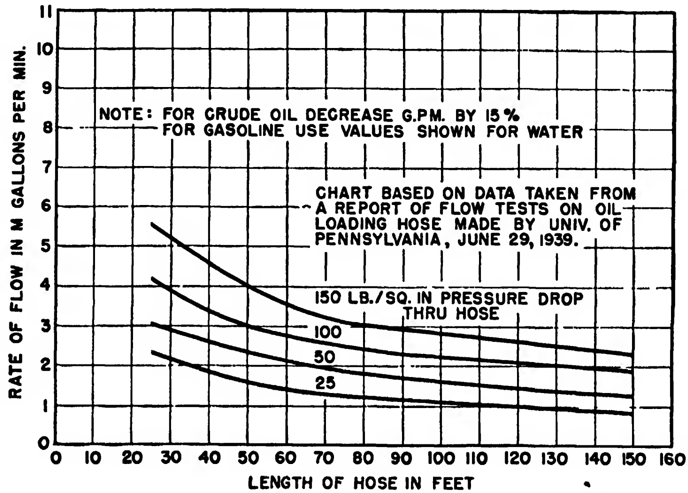


Fig. 26. Flow of water in a 4-inch smooth-bore hose in a straight position with temperature at 63°F.

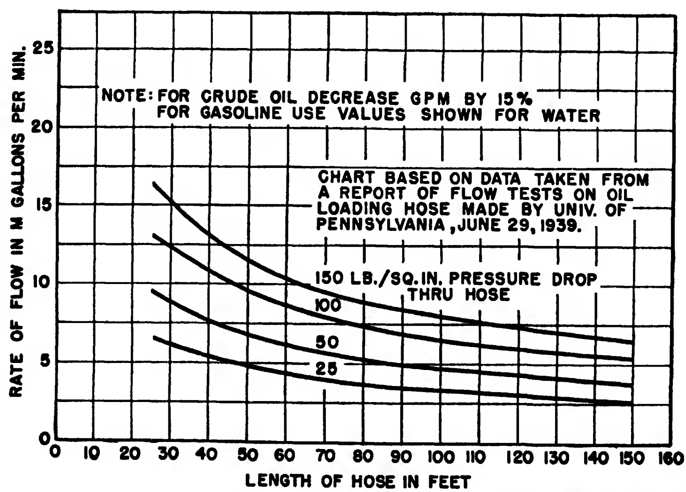


Fig. 27. Flow of water in 6-inch smooth-bore hose in a straight position with temperature at 63°F.

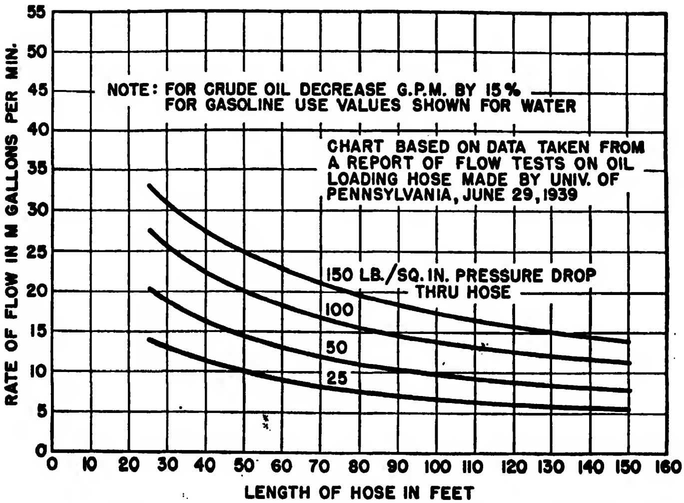


FIG. 28. Flow of water in an 8-inch smooth-bore hose in a straight position with temperature at 63°F.

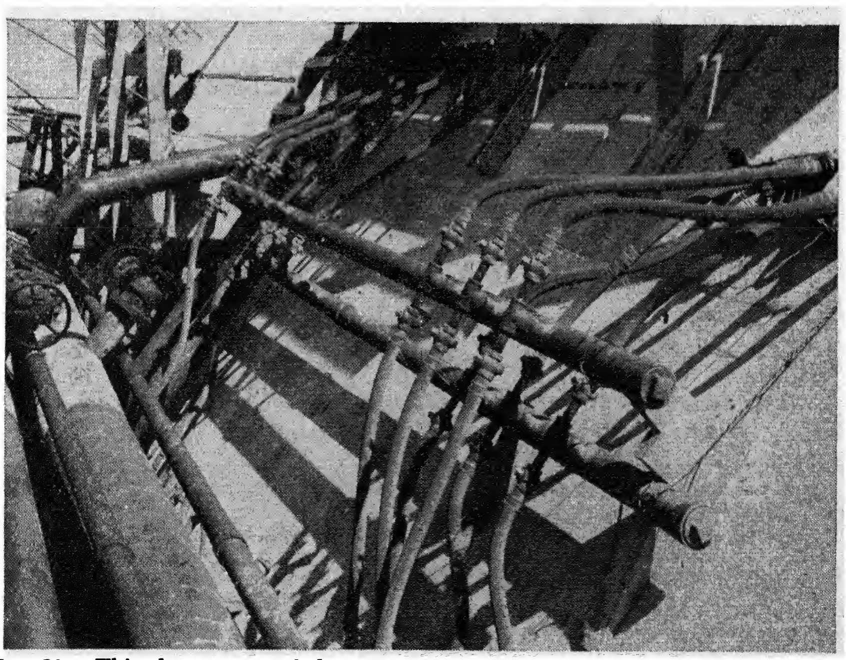


FIG. 29. This shows some of the 90,000 feet of 1-inch rubber water hose used for artificially cooling the concrete during construction of Shasta Dam. Without such cooling, many years would have been required for the dam to reach atmospheric temperature. (*Photograph from U.S. Bureau of Reclàmation.*)

Fig. 30. Hydraulicking loose silt at Shasta Dam preparatory to drilling. A 3-inch manifold hose is shown in foreground; the smaller hose is a 1-inch air hose. (*Photograph from U.S. Bureau of Reclamation.*)

TABLE 34. JETTING-HOSE DATA

Size (I.D.), in.	*No. of plies**	*Wt., lb/100 ft*	*O.D., in.*	*Working pressure, psi*
2	6	160	$2^{13}/_{16}$	250
2½	7	220	$3^{13}/_{32}$	250
3	8	270	$3^{31}/_{32}$	250
4	7	370	5 ⅛	250

* Braid is counted as one ply, although in strength it is equivalent to two plies of duck.

being replaced cannot be used as guide, the hose manufacturer should be supplied with adequate information concerning service requirements and conditions. Any reliable manufacturer can be depended upon to select and use the rubber compounds and other materials that will meet the customer's requirements most satisfactorily. In no case should it be necessary for the customer to make rigid specifications concerning such details as the kind of rubber or type of compound to be used. To do so

might rule out the use of some new and superior compound known to the hosemaker but not to the prospective user.

TABLE 34*a*. FLUID PRESSURE LOSS CHART*
Loss in psi per 100 ft of hose

Flow, gal/min	*Actual inside diameter, in.*							
	½	¾	1	1¼	1½	2	2½	3
5	28	3 9	1	0.3				
10	100	14	3.4	1	0.5			
20		63	13	4.1	1.8			
30			26	9	3.7			
50			67	23	9.5	2.3		
75			.	48	20	4.8	1.6	
100				83	34	8.3	2.8	1 2
150				.	72	18	6	3
200				.	. .	30	10	4.3
250					. . .	46	15	6.5
300						64	21	9

* Above chart is for flow of water through smooth lined rubber hose laid out straight. It is based on Hazen-Williams formula $V = 1.318CR^{0.63}S^{0.54}$, taking C as 140.

TUBING[1]

Rubber tubing is made from crude and American-made rubbers, and rubberlike tubing is made from various plastic materials. Tubing is formed by an extruding or tube machine and has no reinforcement. Tubing sizes (inside diameter) generally run from 1⁄32 to 1 inch, in 1⁄32-inch steps. Wall thicknesses generally vary from 1⁄32 to 3⁄16 inch, in 1⁄64-inch steps. Various compounds are available to meet numerous requirements, and the tubing manufacturer should be consulted for recommendations concerning specific tubing uses in newly designed products, etc.

The weight per unit length of rubber tubing depends on the compound density, inside diameter, and wall thickness. The following table of weight factors applies to American-made rubber tubing.

KOROSEAL TUBING. This is made in continuous extruded lengths with no reinforcement. Some characteristics are given in Tables 36 and 37.

WRAPPED TUBING. This is wrapped in cloth while being vulcanized and consequently has a distinctive cloth texture on its surface. It generally is carried as a warehouse item in 12-foot lengths and sizes ranging

[1] See also latex tubing, p. 70.

TABLE 35. WEIGHT FACTORS—AMERICAN-MADE RUBBER TUBING
Multiply weight factor by specific gravity to obtain weight per hundred feet.

I.D., in.	*Thickness of wall, in.*										
	1/32	3/64	1/16	5/64	3/32	7/64	1/8	9/64	5/32	11/64	3/16
1/32	0 265	0 499	0 798	1.16	1.60	2.09	2.69	3.29	3.99	4 75	5 58
1/16	0.399	0 712	1 06	1.50	1.99	2.56	3.19	3 89	4 65	5 48	6 38
3/32	0.533	0.889	1 33	1.83	2.39	3.03	3.72	4.49	5 32	6 22	7 19
1/8	0 663	1.10	1.60	2.16	2 79	3.49	4.25	5 09	5 98	6 95	7 98
5/32	0.798	1.30	1.86	2.49	3.19	3.95	4.79	5.68	6.65	7.68	8.78
3/16	0.932	1.50	2.15	2 83	3 59	4 42	5.32	6.29	7.31	8.42	9 58
7/32	1 06	1.70	2 39	3 16	3 99	4 89	5.85	6.88	7.98	9 14	10 38
1/4	...	1 89	2 66	3 49	4.39	5.35	6.38	7.48	8.65	9.88	11 17
9/32		2.09	2 93	3.82	4.79	5.82	6.90	8.08	9.31	10.61	11 97
5/16		...	3 19	4 16	5 19	6 29	7.45	8.68	9 98	11 34	12 77
11/32			3.46	4.49	5 59	6.75	7.98	9.28	10.64	12.07	13 57
3/8			3.72	4 83	5.99	7.22	8.52	9.88	11.31	12.80	14 37
13/32			3 98	5.16	6 39	7.68	9.04	10.47	11.97	13 54	15.16
7/16			4 26	5 49	6.79	8.15	9.58	11.07	12 64	14 26	15 96
15/32			4 52	5.82	7.18	8.61	10.11	11.67	13.30	15 00	16.76
1/2			4 79	6 15	7.58	9 07	10.64	12.27	13.96	15.73	17.55
17/32			5 05	6 48	7.98	9.54	11.17	12.87	14.63	16 46	18 35
9/16			5 32	6 82	8.38	10.01	11.71	13.47	15.30	17 19	19.15
19/32			5 58	7.15	8.78	10.47	12.24	14.06	15.96	17 92	19 95
5/8			5.85	7 48	9 18	10.94	12.77	14.66	16.63	18 66	20 75
21/32			6.12	7 82	9.58	11.41	13.30	15.27	17.29	19 39	21.55
11/16			6 39	8 15	9.98	11 87	13 83	15.86	17.96	20.12	22 35
23/32			6.65	8 48	10 38	12 34	14.37	16.46	18.62	20.85	23 14
3/4			6.92	8 81	10 77	12.80	14.90	17 06	19 28	21 58	23 94
25/32			7 18	9 14	11 17	13.27	15.43	17.65	19 95	22 31	24 73
13/16			7 45	9 48	11.57	13.73	15.96	18.25	20.62	23 03	25.54
27/32			7 72	9 81	11.97	14.20	16.49	18.86	21 27	23 78	26.34
7/8			7 98	10.14	12.37	14.66	17.02	19.44	21.95	24 51	27.14
29/32			8 25	10 47	12.77	15.13	17 55	20.05	22 61	25 24	27 93
15/16			8 51	10.80	13.17	15.58	18.09	20.65	23.28	25 97	28 73
31/32			8 77	11.14	13 56	16 06	18.62	21.25	23.94	26 70	29 53
1			9 04	11 46	13 96	16 53	19.15	21 85	24 61	27 44	30 33

TABLE 36. KOROSEAL TUBING

Hardness	70 to 78 durometer at 85°F (29.4°C)
Color	Dull black
Specific gravity	1.31
Working pressure	50 psi at
Temperature range	To 120°F (49°C)
Vacuum service	Superior to rubber
Diffusion (gas)	Negligible
Odor	Negligible
Sulfur content	None; can be used with silver, brass, etc.
Chemical properties	Not swelled by oils and other rubber solvents. Unaffected by strong corrosives, etc. (see Chap. 23)
Limitations	Standard grade of industrial Koroseal tubing is not suitable for use in contact with food. Special grades can be made for such use
Cold flow	Slight. Tubing may increase somewhat in diameter under continuous pressure

TABLE 37. STOCK SIZES OF KOROSEAL TUBING

Size (I.D.), in.	*Wall, in.*	*Wt., lb/100 ft*
1/8	3/32	4.11
3/16	1/16	3.24
3/16	3/32	5.24
3/16	1/8	7.59
1/4	1/16	4.02
1/4	3/32	6.37
1/4	1/8	9 07
3/8	1/8	12.9
1/2	1/8	14.9
1/2	3/16	24.1
3/4	3/16	32.8

Tolerances:
Inside diameter . . . . ±1/64 in.
Wall thickness . . . . ±1/64 in.

from 1/8 to 1½ inches inside diameter, with a wall thickness of 1/16 to 1/4 inch and more. The maximum outside diameter is generally 2 inches. This tubing is used in laboratories, on milking machines, and wherever else a serviceable tubing within the size range is required.

WIRE-INSERT TUBING. This type is of all-rubber construction having a spirally wound steel wire reinforcement between the tube and cover. Otherwise it is similar to wrapped tubing. It is usually sold in 12-foot lengths. It is used in airplane De-Icer installations, for washing machine drain hose, and wherever else bending without flattening or breaking is important.

HOSE FITTINGS

A hose cannot be used with maximum efficiency or safety unless its couplings or other fittings are of the proper type and are attached correctly. Some representative couplings are listed below.

SHANK-TYPE COUPLINGS. These have stems or shanks that fit inside hose tubes and have ridges or corrugations to increase holding power between them and the hose.

Short Shank or Common Couplings. These are suitable for such service as suction and water pressures up to 50 psi. The hose is anchored to the shank with compressed metal ferrules applied at the factory or in the user's shop; with banding devices, bent wire clamps, strap clamps secured by bolts; or with some other clamping arrangement.

Long Shank Couplings. These are used for air and steam pressures up to 50 psi and water pressures up to 100 psi. The corrugated shanks are long enough to permit the use of two clamps on each hose end. Some

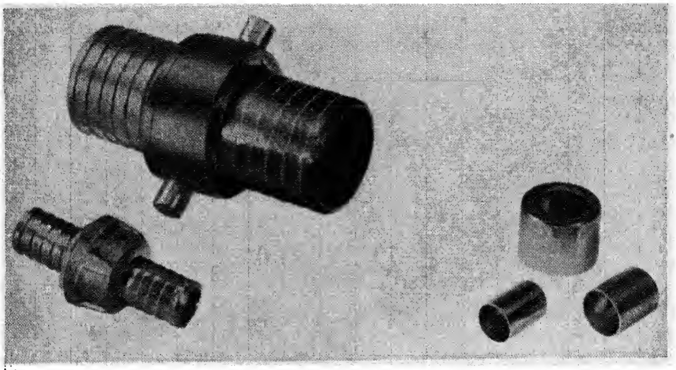


FIG. 31. Short-shank brass couplings. Sizes 1-inch and smaller have gripping flutes on female swivel (*lower left*); sizes over 1-inch and including 2½-inch have lugs on female swivel (*upper left*); 3-inch and larger sizes have lugs on both portions. Brass ferrules (*lower right*) are used to clamp ends of factory-coupled hose 1-inch and smaller to shanks; a single bolted clamp secures each end of larger hose.

of the ridges on the coupling shanks may be made larger than the rest to provide shoulders for improving clamp action.

Long shank couplings usually have hexagon nuts on male and female parts in order to facilitate tightening and loosening. Short shank couplings of small diameters may have gripping flutes on the female swivel and in larger diameters (over 1 inch), pin lugs on male and female swivels.

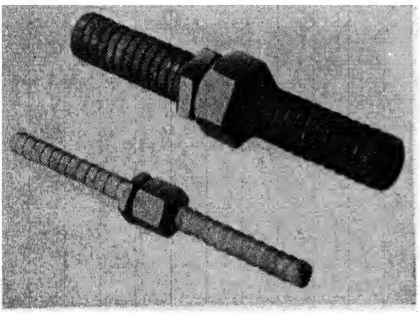


FIG. 32. Long-shank cast-brass couplings. The hexagonal portions permit ordinary wrenches to be used for tightening and loosening. Clamps are used to secure hose to shanks.

HIGH-PRESSURE COUPLINGS. For maximum safety when handling steam, air, or water under extreme pressure, special high-pressure couplings are employed. The clamps that encircle the hose ends are attached to the nipples in such a way that it is impossible for a nipple to blow out of the hose as long as its clamp remains intact. Usually a length of hose is equipped with female high-pressure couplings on both ends unless male couplings (sometimes called nipples) are specified.

Washers made of rubber or plastic are commonly used in couplings. Ground joint couplings have, in the female spud, a copper seat that produces a seal without the aid of a washer and with less tightening force than required for washer types. Various quick-acting heads have been devised. In one type, a gasket forms a seal, and a nail, cotter pin, or short piece of wire locks the heads together; couplings for hose from 3/8 to 1 inch have heads that are the same size, permitting hose sections of two different diameters to be connected.

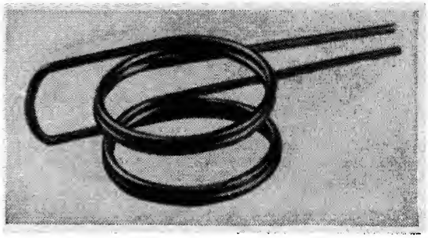


FIG. 33. A wire-type hose clamp. The "hairpin" of wire is applied by forcing the wire ends through the loop, turning them back, and bending them toward the hose to lock them. A special tool is used for installing this clamp. Wire clamps are used on hose from 3/4 to 6 inches outside diameter.

CLAMPS. Common types include cast or stamped brass bands having ends pulled together by bolts, single- or two-bolt malleable iron clamps for hose sizes over 3/4 inch, clamps made by wrapping hairpin-shaped pieces of wire around hose and anchoring ends with aid of special tool and suitable for short- and long-shanked couplings but not recommended for steam service, various kinds of flat-band clamps such as "Punch-Lok" (described below) which are tightened and fastened without the use of bolts, and solid ferrules that are crimped to anchor them and impose pressure on hose.

FIG. 34. Standard one- and two-bolt malleable-iron and brass hose clamps for hose 3/4 inch inside diameter and larger.

Punch-Lok Clamp. This type consists of a band of high-tensile-strength steel and a sliding sleeve. The band is wrapped twice around a hose to clamp it to the nipple stem, and the sleeve is anchored by making a punch mark that extends through outer layer of sleeve and the double thickness of the band, forcing them into an indentation in inner layer of the sleeve. The Punch-Lok clamp takes the place of bolted clamps. The inside diameter of clamps ranges from 3/4 to 6 inches. Standard-duty

steel bands are 0.020 by ⅜ inch and 0.023 by ⅝ inch. Heavy duty steel bands are 0.030 by ⅝ inch. They are available also in Everdur alloy in same sizes as standard steel. Clamps are not recommended for steam

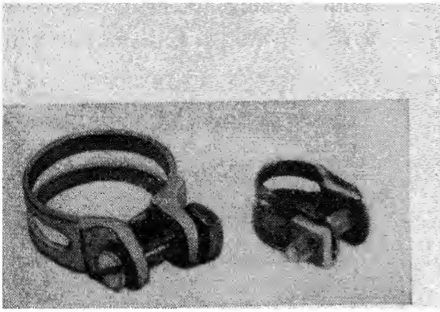


Fig. 35.

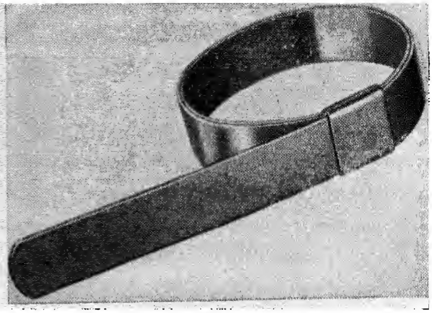


Fig. 36.

Fig. 35. Simple bolt-type hose clamps for ¾-inch and smaller hose. The one at the left is of cast brass; the one at the right, stamped brass.

Fig. 36. A Punch-Lok hose clamp. A strip of high-tensile steel is wrapped twice around the hose, threaded through the flat sleeve, and locked by making a punch mark in the sleeve. These clamps, available also in stainless steel and a copper alloy, can be used for joining electric cables, binding wooden parts, and for numerous other purposes.

hose. For use with Punch-Lok clamps, various hose fittings having properly grooved shanks are available.

In high-pressure service, precautions must be taken to prevent a coupling from being blown out of the hose, as has already been mentioned. Therefore various kinds of special clamping arrangements have been worked out. The Boss high-pressure coupling has a clamp attached to each nipple, at the base of the shank. It extends back over the hose and is tightened by bolts. This coupling is suitable for high-pressure air, steam, or spray hose. In another type, the clamps engage anchor lugs extending back from the coupling heads.

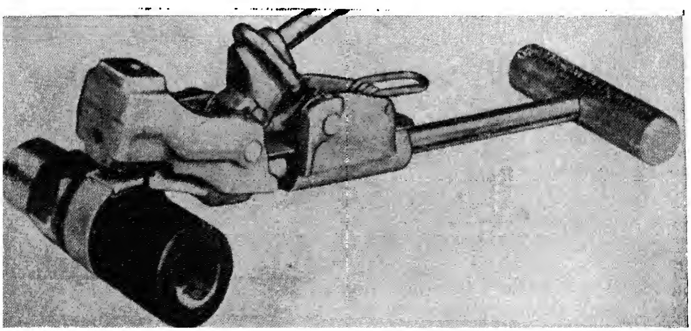


Fig. 37. Special tool for installing Punch-Lok clamps.

Attaching Shank-type Couplings. On high-pressure hose it is extremely important that couplings be attached properly, for failure may cause serious injury or damage. Whenever possible, fittings should be attached to new hose at the factory. When the user installs his own fittings, the following steps should be observed:

1. Round ends of stems to a smooth radius, and remove all sharp burrs, edges, and points from other parts of stems.

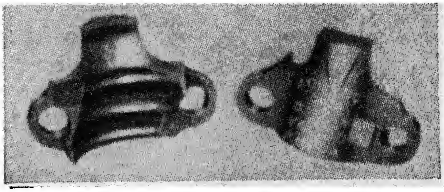


Fig. 38. With clamps such as these, a stem-type hose coupling can be anchored more securely. The clamps grip the hose cover and have lugs that engage a groove in the portion of the coupling extending beyond the hose end.

2. Cover inside of hose and coupling stem with rubber cement or thick soap solution.
3. Clamp coupling in vise, and force hose over its stem. Do not drive coupling into hose with mallet or hammer.
4. When coupling stem is too large to enter hose, either machine it to size on a lathe or use a smaller-stem coupling. Never ream out inside diameter of hose to fit an oversize stem.
5. When there is danger that water will enter around end of hose and soak along fabric plies to cause eventual damage, either use a hose capped by a rubber covering over fabric ends or apply several coats of rubber cement to hose end. When coupling is of seat or socket type, cut hose end square so it will seat tightly. This prevents liquid from leaking between hose cover and tube.

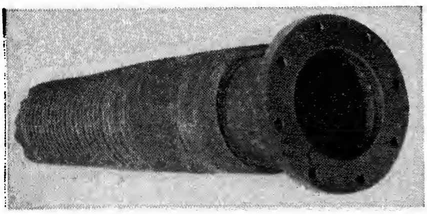


Fig. 39. This oil hose and its nipple were vulcanized into a single unit, making it virtually impossible for the nipple to pull or blow out.

6. Use clamps of proper size. When they are drawn tight, there should be some space between lips to permit later take-up. Clamps are best held in a special hose clamp vise. Do not let end of coupling extend more than ½ inch beyond nearest clamp edge.
7. If hose is wire-wound, bend end of wire around until it lies parallel to hose axis and can be held securely by the clamp.
8. Mount hose so it does not hang in an unnatural position. This means that it should be attached so it is suspended vertically. When the hose is connected in any other way, its weight may impose a damaging strain in the vicinity of the coupling.

Special rubber cements for use on hose coupling stems are available.

Iron-pipe Nipples

Sections of large hose for oil, molasses, heavy suction, and other services are commonly fitted with nipples made from standard iron pipe. The outer end of the nipple has a standard pipe thread, so it can be screwed into flanges. The inner portion of the nipple has a rounded end and is either smooth or provided with clamp grooves or ridges. One, two, or three clamps may be used. There is a four-clamp combination in which one clamp is bolted directly to the iron nipple just beyond the hose end and is secured by anchor bars to one or more of the other clamps. The anchor bars prevent the hose from pulling off the nipple under high strain or pressures, as in oil

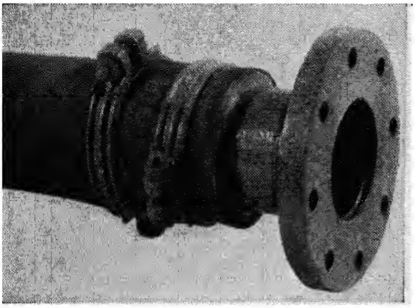


Fig. 40. A two-clamp iron-pipe nipple installed in the end of a hose and fitted with a cast-iron flange.

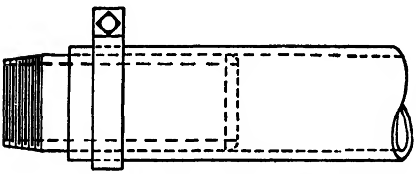


Fig. 41*a*. Iron-pipe hose nipple of the ungrooved, single-clamp type.

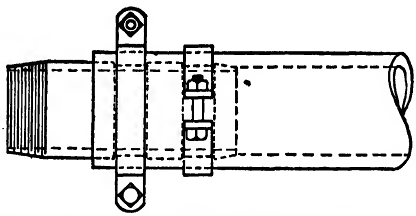


Fig. 41*b*. Iron-pipe hose nipple grooved for two clamps.

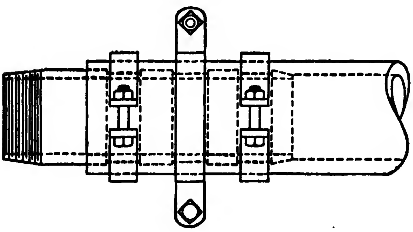


Fig. 41*c*.

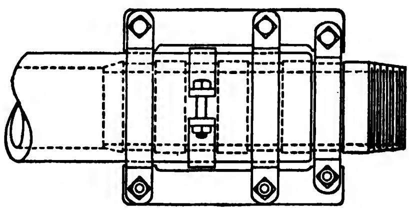


Fig. 41*d*.

Fig. 41*c*. Grooved iron-pipe hose nipple, three-clamp type.
Fig. 41*d*. Anchor-bar type of iron-pipe hose nipple. The nipple is grooved for three clamps encircling the hose and for a fourth clamp that encircles the nipple only and is joined to two of the other clamps by anchor bars.

and sand-suction hose service where the hose supports the weight of pipes or strainer. There is a built-in type of iron-pipe nipple in which the hose is

secured directly to the ridged portion of the nipple, no external clamps being required. This type is particularly suited to oil suction and discharge lines and to other suction and large-diameter hose.

"All-rubber" Hose Joints

A rubber-to-rubber seal with no restriction of inside diameter is produced by a hose joint called Flexseal. Ends of the hose are enlarged by a built-on, fabric-reinforced bead. Steel rings slipped over the hose press against this bead. The two rings of joined hose ends are clamped together by bolts, like pipe flanges, and this forces the hose ends tightly together. This type of coupling permits maximum flexibility, is useful in all suction service and at pressures up to 125 psi, and is particularly adapted to hose carrying acids or other corrosive liquids and to large-diameter discharge or suction hose handling abrasive materials. The Flexseal joint replaces ordinary couplings or nipples.

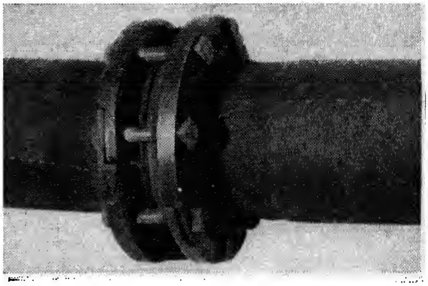


Fig. 42. Flexseal hose joint. The hose is flared by building into each end a rigid steel ring of angular cross section. Two flared ends are compressed together by split flanges drawn toward each other by bolts. The seal will withstand test pressures of more than 500 psi.

The end of a hose arranged for a Flexseal coupling can be attached in a leakproof manner to the end of a pipe of matching diameter equipped with a flange. If the pipe is rubber-lined, chemicals or other materials are carried from hose to pipe and vice versa without touching metal. By coupling a short length of rubber hose between pipe ends, a vibration-absorbing joint is produced. By arranging two lengths of pipe or rod so they can be forced together by clamps or screws, the rubber section can be made to function as a pinch valve.

Expansion-ring Couplings for Fire Hose

The main part of this coupling fits over the hose end, and the hose is forced against its inner surface by an expansion ring. This type is used mainly on unlined and rubber-lined fabric fire hose. There is considerable variation in the specifications of fire-hose couplings. For one thing, thread size is not universally standardized, and several communities have their own particular fire-hose threads. It is not safe to use couplings whose tailpieces do not match the outside diameter of the hose.

Couplings for Gasoline-tank, Distillate, Fuel-oil Hose

Couplings for this service must be sturdy, easily attached, and permanent. They are suitable for tank-truck hose other than cotton-covered, metal-lined; for airplane refueling lines; and for all types of fuel-oil and distillate hose. Couplings normally used are featured by short over-all length, full-flow passage, adaptability to various wall thicknesses and outside diameter, and positive grip. Couplings consist of ridged flow tube, which is part of the male or female section, and a smooth ferrule fitting the outside diameter of hose. Expansion of the flow tube with a taper-nose tool compresses the hose wall between the flow tube and ferrule. Couplings are provided with octagonal nuts. The normal size range is 1 to 3 inches.

End Protector Cap. This is a fitting, made and installed like the male portion of a coupling, which seals the hose end against oil and other fluids.

Gasoline-tank Hose Fittings

A bayonet-type lap joint is used on hose couplings, nipples, and other fittings to permit quick connecting and disconnecting. Time saved by it in unloading gasoline, distillate, or fuel oil may reach 40 per cent. A faucet nipple screws on standard iron-pipe thread (male), permitting attachment of the hose. Fittings are normally available for hose sizes ranging from 1½ to 3 inches.

Tapered Grip-ring Coupling

A type of coupling introduced for tank-truck hose service has withstood test pressure of 2,200 pounds in contrast to old-type couplings that leaked or blew off at 30 to 300 pounds pressure. The outside diameter of the grip ring is tapered, being greater toward the nipple. The threaded compression collar, which encircles the hose, has a matching internal taper. When the collar is tightened, the ring is compressed, its serrations pressing into the hose cover. An increase of pressure in the hose causes the ring to wedge still more tightly against the hose. In old-style couplings, pressure increase caused lines of force to act in an opposite direction, and the coupling failed at a comparatively low pressure. The features of the new coupling enable it to handle an outside-diameter variation of about ¼ inch with but two sets of rings, contrasted to the three or four sets required by older couplings.

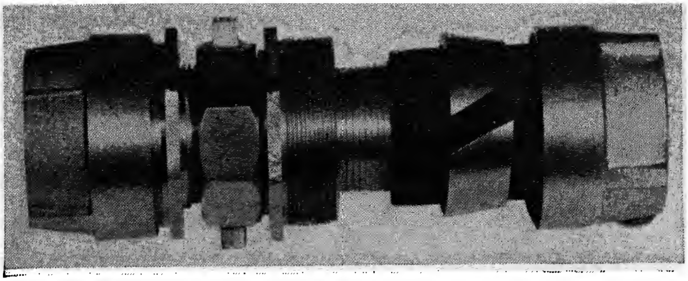


Fig. 43. In this hose coupling, a tapered construction causes a grip ring to wedge more tightly against the side wall of the hose as the pressure increases. In tests of this coupling attached to wire-braided tank-truck hose, it withstood pressures up to 2,200 psi.

Quick-acting Couplers

Virtually instantaneous coupling and uncoupling of air hose are provided by a type of quick-acting coupler designed for heavy-duty and shop air lines. A check unit screws on the male coupling of the air-supply line, and an adapter is mounted in the end of the detachable hose. Practically no air is lost when the hose is attached or uncoupled. The coupler eliminates kinking by acting as a swivel. There are various

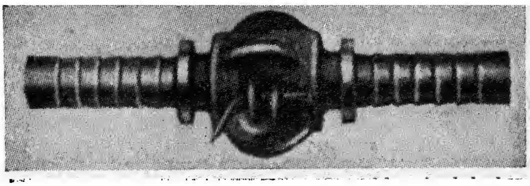


Fig. 44. This quick-acting air-hose coupling has identical halves locked together with a nail, wire, or cotter pin.

other types of quick-acting air-hose couplings. One has identical heads for hose sizes ⅜ to 1 inch, inclusive, and is locked with a nail, wire, or cotter pin.

Welding-hose Couplings

Welding hose for handling oxygen, acetylene, and hydrogen is fitted with female couplings that usually are of special design and have ball seats (see page 271 for additional details).

Grip-ring Couplings

These types of coupling are reattachable. They are designed so that the outer bowl or sleeve of the coupling compresses a split grip ring or

spring (on the hose) against a thin-walled insert. The compressing force is applied by screwing the outer bowl on the threaded outer portion of the insertion part. These types of coupling are generally used for low-pressure service, but recent improvements in one design have increased the range of pressures at which they will perform.

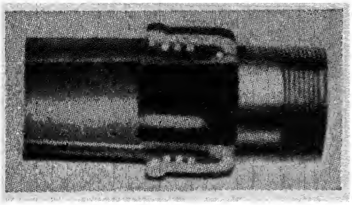


Fig. 45. A sleeve-type coupling for fuel, water, and other services where pressure is not great. The compression collar has a spiral inner groove that screws on a coiled wire slipped over the hose end. The wire may be continued to form a spring guard around the hose near the coupling.

Wire-braid-hose Pressed-on Coupling

The one-time[1] high-pressure coupling is designed for use on hydraulic hose that is reinforced with braided wire. The outer covering of the hose either is removed near the end, exposing the reinforcing wire, or is ground away nearly to the wire. As the coupling is swaged into position, the outer shell is compressed and forced into the wire mesh and into grooves on the inside of the coupling shell. Barbed steel inserts in the tube prevent reduction of flow and permit the hose wall to be held under compression. These couplings require special attaching devices.

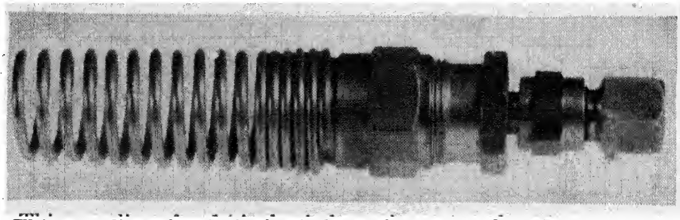


Fig. 46. This coupling, for ¼-inch air hose, is equipped with a spring guard that helps reduce hose breakage near the coupling.

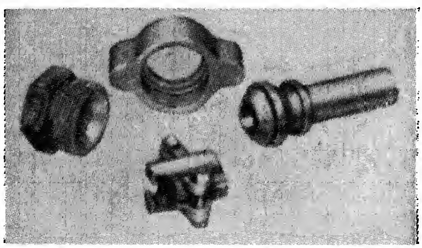


Fig. 47. Parts of a ground-joint coupling in which a highly finished copper seat effects a seal without the use of a washer.

[1] Not reusable.

The foregoing coupling devices do not include all the types that have been made or are available, but they may serve as an indication of what the hose user has at his disposal.

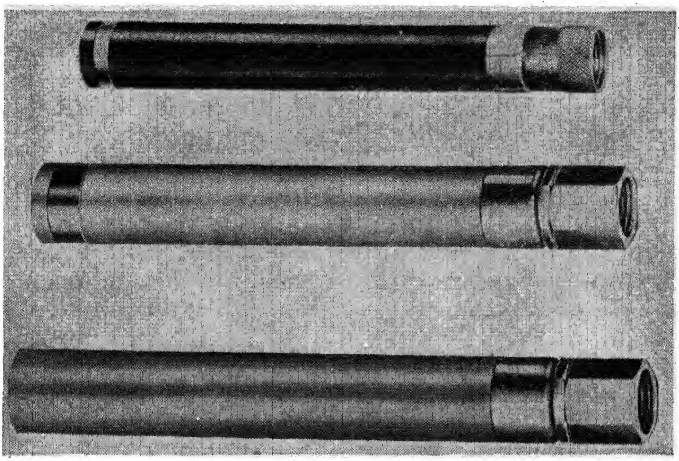


FIG. 48. Rubber hose nozzles. The lower one has an open end for unrestricted full-volume flow; others have spray tips that produce forced, concentrated streams.

FLANGES

Hose sections equipped with nipples (male threads) are joined with the aid of flanges that are screwed on the nipples and then bolted together with a gasket between their faces. Flanges normally have a standard tapered iron-pipe thread.

FIG. 49. Lonn Rubber Blow Gun, which is used like any hose nozzle for directing air or fluid. Flexing the rubber portion of the gun operates an internal valve for controlling flow. The threaded brass tip is for attaching extensions and accessories. (See Fig. 50.)

NOZZLES

Nozzles for fire and garden hose are normally made of brass. The garden-hose type usually is made so the water can be turned on and off as desired. Rubber nozzles are used in creameries, paper mills, canneries and wherever else a metal nozzle might damage machinery. Numerous varieties of blow-gun nozzles are used on air lines.

FIG. 50. This rubber nozzle, similar in design to that shown in Fig. 49, has a soft tip to prevent scratching or otherwise damaging machinery, polished surfaces, etc., and to eliminate static sparks. Metal portion is brass.

LONN RUBBER BLOW GUNS

These are special valves used like ordinary nozzles on water and air hose. The valve is opened or closed merely by flexing the nozzle, this action operating an internal trigger arrangement. Water guns are avail-

FIG. 51. These are but a few of the countless ways rubber hose is used with air or liquid spray guns.

able for producing a concentrated, high-force stream or a soft, open-volume stream. Air guns are available for straight blowing service up to 200 psi pressure and in a combination blow gun and sprayer for applying kerosene and other cleaning fluids, paint, etc.

STANDARD HOSE TOLERANCES

Mandrel-cured: Wrapped-fabric, or Horizontal Braided Hose

1. Inside diameter:
   a. 1/8-inch hose shall have a tolerance of ±1/128 inch.
   b. From 1/8-inch up to and including 3/8-inch hose, the tolerance shall be ±1/64 inch.
   c. From 3/8-inch up to but not including 4 1/2-inch hose, the tolerance shall be ±1/32 inch.

   - *d.* Hose 4½ inches and over shall have a tolerance of plus 1/16 inch and a minus tolerance of 1/16 to ¼ inch, depending on length and size of hose. For wire inserted hose, the measurements will be taken at the soft ends.
   - *e.* Hose with enlarged ends shall have a tolerance of ±1/16 inch, as measured at the enlarged end.
   - *f.* Dredging sleeves 12 inches and under shall have a tolerance of ±1/16 inch; dredging sleeves over 12 inches shall have a tolerance of ±⅛ inch.
2. Outside diameter:
   - *a.* Under 1-inch inside diameter, hose shall have a tolerance of ±1/32 inch.
   - *b.* 1-inch hose up to but not including 4½-inch shall have a tolerance of ±1/16 inch.
   - *c.* Hose 4½ inches and over shall have a tolerance of +⅛ inch and −¼ inch, depending on length and size. Hose of this size can be built to a tolerance of ±1/16 inch if required. In such cases, the manufacturer must be informed of the required outside diameter and tolerances.

Molded Braided Hose

1. Inside diameter:
   - *a.* 3/16- to ⅜-inch sizes inclusive of welding, paint, spray, and curb line hose shall have a tolerance of ±3/128 inch.
   - *b.* All other braided hose under 1 inch shall have a tolerance of ±1/32 inch.
   - *c.* All braided hose 1 inch and over shall have a tolerance of ±1/16 inch.
2. Outside diameter:
   - *a.* All braided hose under 1 inch in nominal inside diameter shall have a tolerance of ±1/32 inch.
   - *b.* All braided hose 1 inch and over in nominal inside diameter shall have a tolerance of ±1/16 inch.

Cotton Rubber-lined Fire Hose

1. Inside diameter:
   - *a.* All single-jacket fire hose shall have a tolerance of +1/16 inch and −0.
   - *b.* Double-jacket hose under 2½ inches in inside diameter shall have a tolerance of +1/16 inch and −0.
   - *c.* Double-jacket hose over 2½ inches in inside diameter shall have a tolerance of +3/32 inch and −0.
2. Outside diameter:
   - *a.* All single-jacket hose shall have a tolerance of ±1/32 inch.
   - *b.* Double-jacket hose 2½ inches and under in inside diameter shall have a tolerance of ±1/32 inch.
   - *c.* Double-jacket hose over 2½ inches in inside diameter shall have a tolerance of 3/64 inch.

Woven Hose with Wire Filler

1. Inside diameter:
   - *a.* All hose under 1 inch shall have a tolerance of ±1/32 inch.
   - *b.* All hose from 1 to 3 inches inclusive shall have a tolerance of ±1/16 inch.
   - *c.* Hose over 3 inches shall have a tolerance of ±3/32 inch.
2. Outside diameter:
   - *a.* All hose under 1 inch in nominal inside diameter shall have a tolerance of 1/32 inch.
   - *b.* All hose from 1 to 3 inches inclusive nominal inside diameter shall have a tolerance of ±1/16 inch.
   - *c.* All hose over 3 inches nominal inside diameter shall have a tolerance of ±3/32 inch.

Tolerances given are for the hose only and do not take into consideration hose with coupling.

Chapter 13

RUBBER IN HYDRAULIC EQUIPMENT

The smooth functioning of modern hydraulic systems often depends on rings, cups, and other parts made of rubber. When oils, gasoline, and other substances that cause excessive swelling of crude rubber and some American rubbers are to be handled by the system, such parts must be made from oil-resisting compounds.

Typical hydraulic and similar equipment parts molded from oil-resisting compounds include O-ring, V-ring, and U-cup hydraulic packings; bellows-type boots; piston cups; and carburetor and accumulator diaphragms.

O-RING PACKING. This is a ring-shaped molded part used as seals in hydraulic systems on airplanes, farm equipment, snowplows, road-building machinery, and such other products as machine-tool controls and clamping devices.

Material. It is made of an oil-resisting American-rubber compound such as Ameripol.

Characteristic Dimensions. Inside and outside diameters are uniform. When the piece is cut on a radial plane, the resulting cross section is a circle.

Sizes. There is a considerable assortment of O-ring packing sizes that meet Army and Navy specifications. Those designed for use on moving parts such as pistons of actuating cylinders are numbered AN-6227-. Those designed for use as static seals and not for use on moving parts are numbered AN-6230-; they are not made to such close tolerances as the 6227 series.

TABLE 1. TYPICAL SIZE RANGES OF O-RINGS

Part No. range	*Cross section range, in.*	*I.D. range, in.*
AN-6227-1–AN-6227-56	0.070–0.275	0.114–4.975
AN-6230-1–AN-6230-23	0.139	1.609–4.359

V-RING PACKING. Hydraulic V-packings are used in the same types of machinery as are O-rings.

Material. V-rings are made of an oil-resisting American-rubber compound such as Ameripol.

Characteristic Dimensions. Inside and outside diameters are uniform. When the ring is cut on a radial plane, the resulting cross section is V-shaped.

Sizes. The following summary shows typical size ranges for V-rings made to Army and Navy specifications:

TABLE 2. V-RINGS

Part No. Range	*Cross section range, in.*	*I.D. range, in.*	*O.D. range, in.*
AN-6225-1–AN-6225-59	$\frac{3}{16}$–$\frac{1}{2}$	$\frac{1}{8}$–$6\frac{1}{4}$	$\frac{1}{2}$–$7\frac{1}{4}$
Odd dimensions not covered by the 6225 series			
40B629-5-014–40B629-24-924	$\frac{5}{32}$–$\frac{3}{4}$	$\frac{7}{16}$–$9\frac{3}{4}$	$\frac{3}{4}$–$11\frac{1}{4}$

U-CUP PACKING. This is similar to the V-ring, but the cross section has more of a U-shape.

PISTON CUP. This is a molded rubber disk with turned-up edge, resembling a beverage bottle cap in shape. It is used as a piston seal where pressure of compressed liquid or gas pushes the cup rim out against the cylinder. It is made of a crude rubber or American-rubber compound such as Ameripol.

HYDRAULIC BOOT. This is a molded rubber part shaped somewhat like a camera or accordion bellows. It is used as a seal between the piston rod and cylinder of hydraulic brake units and similar equipment. The bellows construction permits movement without breaking the seal. It is made of an oil-resisting American-rubber compound such as Ameripol.

Rubber manufacturers keep on hand molds for many of the standard O-rings, V-rings, and other hydraulic equipment parts. Often the designer who intends to use such a part in a new product may select it from such stock sizes, thus saving time and money. If there is no existing stock item that will do, rubber manufacturers are prepared to make or otherwise obtain special molds when quantities ordered justify the cost. The designer should consult rubber manufacturers in the early stages of his design development, for often it is possible to alter dimensions of other parts slightly so that stock rings, cups, or boots can be used.

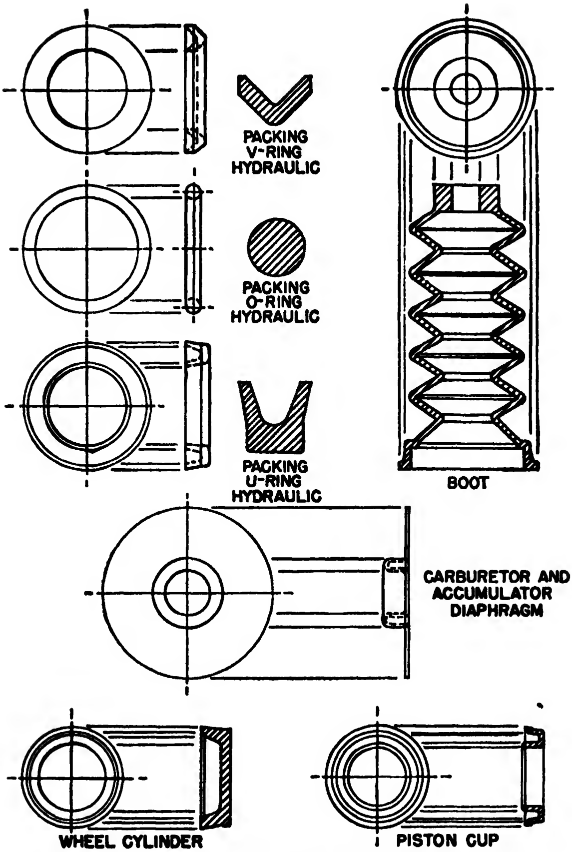


FIG. 1. Typical forms of rubber hydraulic packings.

Rubber Characteristics

Properties of Nitril-type American-made rubber, used widely for making hydraulic equipment parts, are given in Chap. 2, but the more important ones are summarized here as they relate to service in hydraulic equipment:

Hardness: Same range as crude rubber.

Tensile strength: Maximum in compounds of tire-tread type. Low in pure gum compounds.

Elongation: Approximately same range as crude rubber.

Specific gravity: 1.0. The specific gravity of crude rubber is 0.93, so gravity of Nitril-rubber product may be a little higher than that of similar crude-rubber product.

Odor: Pleasant. Special compounds can be made practically odorless.

Taste: Special compounds can be made practically tasteless.

Color: Various, but black permits highest qualities. Age resistor normally used turns brown or red in sunlight; special nonstaining Nitril (Ameripol) is available.

Elasticity: Lower than for crude rubber.

Permanent set: Compares favorably with that of crude rubber.

Tear resistance: Somewhat less than for crude rubber.

Abrasion resistance: Approximately same as for crude rubber under normal conditions; better in presence of oil and high temperature.

Petroleum-product resistance: Outstanding resistance to oil, gasoline, etc. Maximum swell not over 10 per cent; maximum shrinkage normally not over 20 per cent.

Acetone resistance: Poor.

Carbon-tetrachloride resistance: Good.

Heat resistance: Varies with conditions of exposure, but temperature range in which Ameripol can be considered reaches 200 to 400°F.

Cold resistance: Stiffens below freezing point. Can be flexed 180 degrees at −50°F without cracking.

Light, ozone resistance: Not much better than for crude rubber.

Metal adhesion: By using special cements, Ameripol can be vulcanized to sandblasted brass, etc.

Acid, alkali resistance: About same as for crude rubber.

Aging resistance: Excellent.

TABLE 3. SUGGESTED APPLICATIONS OF NITRIL-TYPE RUBBER IN HYDRAULIC EQUIPMENT

Service	*Durometer Hardness*
U-cup packings	70
V-packings	90
Heat-resisting compounds	75
Hydraulic boots	50
Cork compounds (gasket)	70
Piston cups	60
Aromatic fuel, regular:	
100-octane fuel handling	40
100-octane fuel handling	50
100-octane fuel handling	60
100-octane fuel handling	70
Diaphragms (carburetor and accumulator)	55
Diaphragms (carburetor and accumulator)	80

Chapter 14

LATHE-CUT RUBBER

Under this heading are grouped a number of general and specialty items whose manufacture involves the cutting of rubber on a lathe.

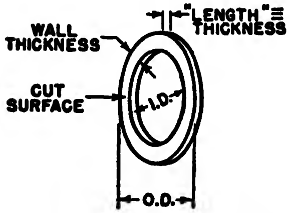


FIG. 1. A typical lathe-cut part showing various dimensions. Rubber gaskets, jar rings, and washers are examples of lathe-cut products.

HAND CUTTING. This method, now made obsolete by automatic machinery for production runs, can be used when small quantities of rubber washers, gaskets, or similar products are being made. The vulcanized rubber is in the form of a tube and is mounted on a wooden mandrel between lathe centers. An ordinary wood-turning lathe can be used. The rubber is revolved at approximately the speed normally used for turning wood of similar diameter. The hand-held cutter is a steel knife shaped like a skew chisel, the cutting edge being at an angle of approximately 45 degrees with the back. Blade size is about 1/16 by 3/8 by 6 inches, and the blade is mounted in a handle large enough to be gripped firmly. The knife is steadied by a T-shaped rest that generally has notches, fitting the blade back, to space the cuts. The operator forces the blade into the revolving rubber cylinder in such a way that a ring-shaped or tubular segment is cut off.

AUTOMATIC CUTTING. Lathe-cut articles are turned out at production rates on automatic lathes that perform the same operations with much greater speed and accuracy. Such machines are produced by the Black Rock Manufacturing Co., Bridgeport, Conn.

Lathe-cut products are distinguished by the following characteristics: (1) generally round in shape. The rubber may be molded and vulcanized into a square or similar shape and forced over a round mandrel for cutting. The cut pieces will resume original form when removed. (2) Usually a uniform inside diameter. (3) Outside diameter generally uniform but may have irregularities such as corrugations, ridges, etc. (4) Inner and outer surfaces usually concentric. (5) Smooth finished ends or faces.

Compounds. An unlimited number of rubber compounds, both natural and synthetic, may be used, but about 100 different ones cover practically all requirements.

Hardness. This varies over wide range, but best results are obtained between 40 and 90 durometer.

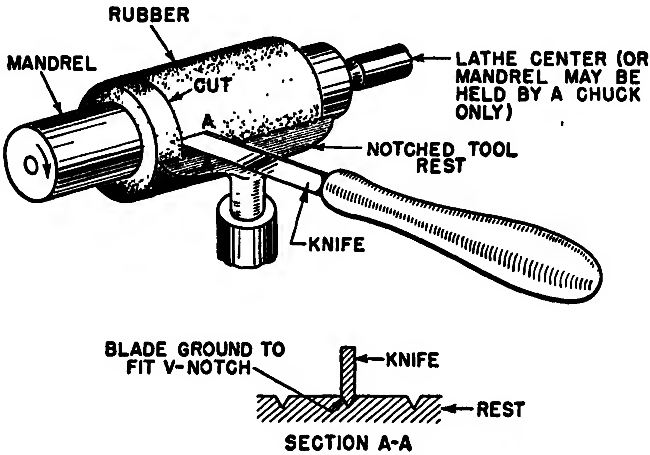


Fig. 2. This shows how mandrel-mounted rubber can be cut on a lathe with a hand-held tool. If the lathe has a carriage, the knife should be clamped in the tool post to permit more precise control.

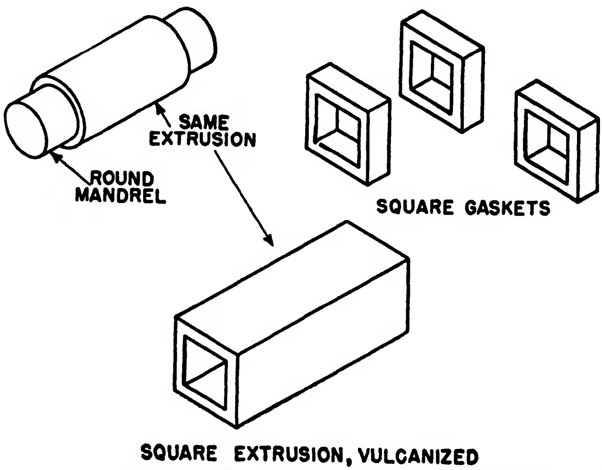


Fig. 3. How a noncylindrical tube can be converted into gaskets or other parts by lathe cutting. Here a square-section extrusion is cut on a round mandrel. Cut pieces resume square shape when removed.

Methods of Manufacture. Generally three distinct methods are used:

1. Stock is extruded on a tube machine, cured on a mandrel to give uniform inside diameter, and cut on a lathe.
2. Stock is extruded, wrapped in wet linen and cured, and cut.
3. Stock is extruded, wrapped and cured, mounted on mandrel and ground to uniform outside diameter, then cut.

Size Range. Although the size of lathe-cut parts is limited only by the equipment available, generally the following ranges prevail:

	Inches
Inside diameter	1/8 –20
Outside diameter	1/4 –24
Wall thickness	1/32– 5
Length*	1/16–24

* Measured between cuts. The "length" of a lathe-cut gasket is its thickness.

Costs: Lathe cutting is one of the least expensive ways of converting a rubber compound into finished products. It assures reasonable dimensional accuracy and a high rate of production and requires no elaborate molds or dies. Short-run or experimental items can be produced quickly and cheaply on conventional wood lathes if desired. Thus an experimental washer or gasket may be made in limited quantities from short lengths of rubber hose or tubing in virtually any carpenter shop.

Tolerances. Dimensional tolerances that can be held in production lathe cutting depend on a number of factors, including the hardness of the compound being cut. Length tolerances depend on the length to be cut and on wall thickness. Wall tolerances depend on the size of the piece and the method of manufacture. Inside-diameter tolerances depend on the size and the quality of the rubber compound. Tables 1, 2, and 3 show representative tolerances for such lathe-cut items as tubes, washers, and gaskets.

Table 1. Wall-thickness Tolerances

Wall thickness, in.	*Unground stock, in.*	*Ground stock, in.**
1/32–1/16	±0.015	±0.003
1/4 –5/16	±0.031	±0.005
1/2 –5/8	±0.036	±0.005
3/4 –7/8	±0.036	±0.007
Over 1	±0.046	±0.012

* Outside diameter ground for uniformity and smoothness.

TABLE 2. INSIDE-DIAMETER TOLERANCES

I.D., In.	Tolerance, In.
High-grade soft compound, durometer hardness to 60	
0 – 1	+0.007 – –1/64
2 33/64 – 4	+0.007 – –3/64
6 1/16 – 8	+0.007 – –3/32
10 1/64 – 12	+0.007 – –5/32
16 1/64 – 20	+0.007 – –1/4
Medium and hard compound, durometer hardness 61 and over	
0 – 2	+0.007 – –1/64
3 33/64 – 6	+0.007 – –3/64
10 1/64 – 12	+0.007 – –3/32
16 1/64 – 24	+0.007 – –5/32

TABLE 3. LENGTH TOLERANCES

Length, in.	*Wall thickness, in.*	*Tolerance, in.*
To 1/4	To 1/4	±0.010
1– 2	To 1/4	±0.018
6–10	To 1/4	±0.047
To 1/4	1/4–1	±0.015
1– 2	1/4–1	±0.028
6–10	1/4–1	±0.054
To 1/4	1 and over	±0.022
1– 2	1 and over	±0.063
4– 6	1 and over	±0.093

TYPICAL LATHE-CUT PRODUCTS

Most items handled by the lathe-cut department of a rubber company are special and are sold on a quotation basis. The customer often specifies the compound to be used, particularly when he is reordering and already knows that a certain compound (as designated by the manufacturer's number) is satisfactory.

FRUIT-JAR AND OTHER SEALING RINGS. These are perhaps the most familiar lathe-cut items. Three types are made: (1) shoulder seal, resting on shoulder of fruit jar; (2) top seal, resting on edge of jar, made in both vulcanized and unvulcanized types; and (3) side seal, which presses against side of container near edge, as on a jelly glass.

SWEEPER BELTS AND SIMILAR BELTS. These are cut from relatively thin-walled, elastic tubing and usually must be held to close limits as to length, elasticity, etc.

WASHERS AND GASKETS. These are ring-shaped pieces, of which the familiar garden-hose washer is an example. Gaskets include those used for sealing joints in flanged pipe lines.

BAND-SAW BANDS. These are rubber rings cut to length on a lathe and cemented to rims of band-saw wheels to cushion blade.

BUMPER AND SPRING RUBBERS. Cylindrical tubes with relatively small inside diameter are used as bumpers on industrial trucks and similar equipment.

FORMING RUBBERS. Cylindrical pieces of rubber are used in conjunction with hydraulic presses for forcing convex sides of such products as cooking utensils and automobile headlamp housings out against mold cavity surfaces.

TYPEWRITER PLATENS. Three types are furnished: (1) unlined, consisting of plain rubber tubes; (2) lined, having a fabric liner around the inside diameter; and (3) cushioned, consisting of soft-rubber layer, fabric reinforcement, and harder outer cover. Platens are cut to length by the manufacturer but are ground to size by the typewriter maker or service establishment.

FEED ROLLS FOR TYPEWRITERS. These are small rolls used to hold paper against platen. The typewriter maker grinds them to the outside diameter required.

CARPET-SWEEPER TIRES AND BELTS. These are cut from thin-walled stock. Tires may be corrugated for better friction properties against floor and brush wheel.

SCOPE. In the lathe-cut department of one manufacturer, some of the production men started to calculate the possible combinations of length, inside diameter, outside diameter, and wall thickness that could be used in making belts, gaskets, and other similar articles. On the basis of $\frac{1}{32}$-inch steps, they soon found themselves in the millions. And then there are at least 100 different rubber compounds available—which boosts the possible combinations into the hundreds of millions.

Chapter 15

RUBBER LININGS

For a great many years, the ability of rubber compounds to resist acids was known and was utilized in such products as hose and tubing. Around the beginning of the present century, some rubber lining was used in wooden tanks. Then, in the 1920's, research men at the B. F. Goodrich Laboratories started looking for a better material from which to make phonograph records—and found a way of bonding rubber to metals so as to give an adhesive strength greater than 500 psi. This method of attaching rubber to metal has become known as the Vulcalock process.

Now rubber linings could be fastened firmly to steel vessels and pipes, thus permitting them to handle corrosive and abrasive liquids that would damage or destroy steel alone. The chemical industry was freed from much of its dependence on glass and other fragile containers. In 1924, a standard steel railway tank car lined with acid-resisting crude rubber became the pioneer unit in a new era of chemical transportation. That car remained in service for many years, long enough to see a wholly new industry—the design and applications of rubber linings and coverings—develop within the parent rubber industry. Today, pipes, tanks, vats, and metal vessels of all kinds are being lined with crude and American-made rubbers and rubberlike plastics.

The chief purpose of a rubber lining is to prevent contamination of contents and provide resistance to chemical action and abrasion. The lining is not designed to contribute anything to the mechanical strength of the metal structure. The tank or other product has to be sufficiently strong in itself to withstand any pressure it will experience. When a vacuum is involved, the metal container has to be tested and approved for vacuum service, because a leak or failure in its structure might cause premature failure of the lining.

Materials to Which Rubber Can Be Bonded

A rubber covering or lining may be attached to various kinds of surfaces, such as the following:

Ordinary Steel.[1] This is the most widely used material for lined containers. The normal working adhesion between crude-rubber lining materials and steel is around 500 psi. Higher adhesions can be obtained with various cements, but it is invariably found that those adhesions are achieved only under conditions not readily applicable to the lining of steel vessels and miscellaneous equipment.

Stainless Steel. In many instances where a designer specifies stainless alloys for tanks and the like, adequate service could be obtained by using rubber-lined containers made of ordinary steel.[1] As the percentage of nickel in stainless alloys increases, the adhesion it is possible to obtain between rubber and the alloy decreases. The percentage of chromium in the alloy is not particularly important with respect to adhesion. Copper, when alloyed with steel, is undesirable in any proportion.

Aluminum. Rubber linings do not adhere to aluminum so well as to steel.

Brass. Rubber linings can be applied to containers made of various kinds of brass, but demand for such construction has been small. From the standpoint of rubber adhesion, the most satisfactory range is 60 to 70 per cent copper, with the remainder made up of zinc and perhaps a trace (up to 1 per cent) of tin; the ideal is around 63 to 65 per cent copper. Rubber can be bonded to brass having copper percentages running from 70 to 80, but the lining material must be specially compounded. In all cases, the rubber-lining manufacturer should be provided with information concerning the analysis of brass vessels he is expected to line.

Wood and Concrete. When required, tanks made of wood can be provided with rubber or plastic linings for holding acids or other chemicals. Wood and concrete are the least desirable for lining because they do not lend themselves readily to the lining application processes, and they cannot be tested electrically for leaks (see page 321). In commercial photographic laboratories, it has been for years the practice to use sinks made of cypress or other wood and to rely on the swelling action of the water to prevent leaking. Some progress has been made in the application of sheet-rubber or plastic linings to such wooden sinks.

Products Commonly Lined

Typical industrial equipments that are commonly lined with rubber include railway tank cars, chemical storage tanks (particularly for acids), pickling tanks, plating tanks, pipes for carrying chemicals, valves for use

[1] By "ordinary steel" is meant such materials as boiler plate, "tank steel," and other mild steels commonly used in making tanks, pipe, etc.

with such pipes, barrels, drums, fume stacks, and containers for handling food products.

Lining Materials

Materials available for lining containers include

Natural crude-rubber compounds.

American rubbers such as GR-S, Neoprene, Butyl, and Nitril.

Rubberlike plastics such as plasticized polyvinyl chloride.

In general, crude rubber is superior to any synthesized lining for most service requirements. Exceptions include the Neoprenes for hydrofluoric acid and oil resistance and Koroseal linings for nitric acid and oil resistance.

Forms of linings include

Soft rubber (crude, GR-S, Neoprene, Butyl, Nitril).

Semihard rubber (crude, GR-S, Nitril).

Hard-rubber compounds, which provide maximum resistance to acids, etc. (crude, GR-S, Nitril).

Combinations of soft and hard rubbers (crude, GR-S).

While Nitril and Butyl rubbers are listed as available, their use in linings is rare and their applicability is very limited. Both present considerable manufacturing difficulties, which, of course, increase cost.

Lining Thickness

Thickness of rubber lining commonly applied to pipe and tanks is as follows:

	Inches
Pipe	$\frac{1}{8}$–$\frac{1}{2}$
Tanks:	
Light duty	$\frac{1}{8}$
Majority	$\frac{3}{16}$
Heavy duty pickling, etc.	$\frac{1}{4}$
Very heavy duty (rare)	$\frac{3}{8}$

The portion of a tank lining directly below a manhole is usually made thicker to resist injuries from measuring rods, dropped tools, and other objects.

Selection of Materials

Material selection involves (1) selecting the metal or other materials from which the container is to be made and (2) selecting the lining compound.

Often an engineer who is not thoroughly familiar with rubber-lined equipment may save money and get a better installation by seeking the aid of a reliable rubber manufacturer who has had extensive experience in this field. It is of prime importance that the manufacturer be given full details about service requirements to be met, so that he can determine the type of lining that will prove best. By such cooperation between supplier and consumer, the utmost results can be obtained from the use of rubber as a lining material. This was true in the days when crude natural rubber was the only type used for linings; now, with so many synthetic materials available, it is more than doubly so.

Although rubber linings can be made to adhere to a variety of materials, steel is usually the first choice because of its many advantages: low cost, ease of fabrication, strength, ease of repair, etc.

From the standpoint of repair, steel is desirable when corrosive materials are being handled. It is characteristic of tanks lined with rubber by the Vulcalock process that when a leak occurs, the damage soon shows up at a spot on the outside surface directly opposite the break. Repairs then can be made before extensive unseen damage is done. For this reason, rubber-lined tanks should be placed so their outer surfaces can be reached at all times for inspection, repair, and painting.

Lining-material Factors. The selection of the lining material may depend on several factors, such as chemical resistance, freedom from contamination of contents, workability of compound, cost, and temperatures to be encountered. While later paragraphs deal with this subject, it can be repeated for emphasis that in most cases the manufacturer of the lining material should be given full freedom in selecting a compound that will meet service requirements most satisfactorily.

Temperature Range. Crude-rubber linings will withstand service temperatures up to 200°F when unsheathed. When a sheathing of bricks is used, the temperature range extends to about 235°F. These maximum temperatures will vary somewhat with specific service conditions. The lining material will withstand more heat than the bond used to join it to the metal, so the maximum temperature figures are really those for the bond rather than the lining. Minimum temperatures for linings are as follows: soft crude rubber, −80°F; Neoprene, −20°F; hard rubber, +35°F.

Installing Linings

Sometimes it is difficult for a potential user of rubber-lined equipment to understand why he cannot buy and install lining materials himself

instead of sending his tanks, etc., to the rubber manufacturer for lining. Perhaps the following outline of the steps in applying a typical rubber lining will help clear the situation:

1. All metal areas to be rubber-covered must be freed of rust and otherwise cleaned until they exhibit a bright, roughened surface. Usually a sand or steel-grit blast is used. After cleaning, there must be enough sound metal left to meet all mechanical-strength requirements.

2. Adhesives are applied to the cleaned surface, much like paint. Several coats, each drying thoroughly, usually are required. Selection and use of these adhesives require considerable experience.

3. Semiplastic, tacky, unvulcanized sheet rubber is applied by hand, and all seams are hand-rolled to ensure good contact. This sheet material is produced by calendering numerous thin plies together to produce necessary thickness and to eliminate any possibilities of porosity. Rivet heads are covered with a preliminary layer of rubber before application of the main sheet.

4. After the lining is in place, it is vulcanized either by placing the entire tank in a large vulcanizing chamber and admitting steam or, in the case of closed tanks, by admitting steam into the lined chamber under pressure. Large, open tanks that cannot be moved into an autoclave can be vulcanized with hot water or steam jets, an operation requiring many hours.

American-rubber materials are more difficult to handle than linings made of crude-rubber compound. In the case of plasticized polyvinyl chloride, vulcanization is not involved. The lining compound is a thermoplastic material, and all seams are heat-sealed.

Sprayed Linings. Soft crude-rubber and soft Neoprene linings can be applied in solution by spray methods. These do not, however, lend themselves to the wide variety of service conditions that can be handled by conventional linings. One reason for this is that the range of lining compounds which can be sprayed is narrower than the range of compounds applied in sheet form.

Hardness of Linings

Hard-rubber linings are in general more resistant to chemicals than are soft linings, but the hard linings are more easily damaged by impact and by temperature changes and are more difficult to repair. In most cases where a hard-rubber lining is necessary, a soft tie gum is placed between it and the metal. Some services require that the hard rubber be bonded directly to the steel, as in centrifugal baskets.

The Triflex lining combines hard rubber's chemical resistance with soft rubber's ability to withstand physical abuse and sudden temperature changes. The lining consists of a layer of hard rubber sandwiched between two layers of soft compound. A special form, Triflex K, is designed for all kinds of plating service except chromium. Seams are made in Triflex lining in such a way that the soft-rubber layers are

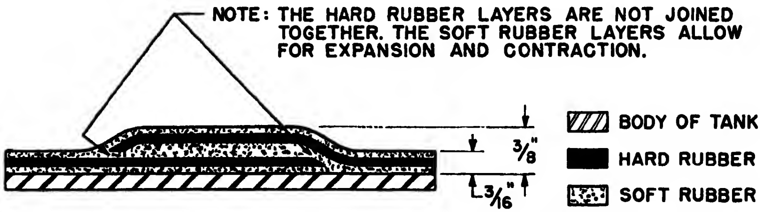


FIG. 1. Section through a Triflex expansion joint in rubber tank lining.

bonded together but the hard-rubber sections are free to move relative to each other.

CHEMICAL RESISTANCE

Although hard rubber has the highest chemical resistance of any crude-rubber lining material, in large-size equipment other factors such as physical abuse, expansion, and contraction may make it necessary to sacrifice chemical resistance to some extent and to use a softer compound. When a hard-rubber lining is an absolute "must," the possibility of cracking and other damage must be regarded as necessary risks.

CRUDE AND AMERICAN-MADE RUBBER. There is a general feeling that American-made rubbers have not proved themselves equal to crude rubber for tank-lining service. Probably this is because the manufactured rubbers have not been used long enough to provide experience comparable to that connected with crude rubber. Eventually, when the technique of using these materials has been developed more fully, such rubbers as Nitril, GR-S, Butyl, and Neoprene probably will be found to have advantages in specific applications and thus will find a place in a well-rounded assortment of tank-lining materials.

POLYVINYL CHLORIDE (PVC). This type of lining is customarily used where it will be satisfactory but where rubber is not. For example, PVC linings will stand up well in tanks holding nitric-hydrofluoric acid mixtures used in pickling stainless steel and nitric acid used for passivating stainless alloys and treating aluminum. PVC linings are also used in chrome-plating tanks and in other services involving strong oxidizing acids that attack rubber compounds.

TABLE 1. CHEMICAL RESISTANCE OF LINING MATERIALS*

Substance†	*Rubber*	*Plasticized polyvinyl chloride*
Acetaldehyde	*P*	*P*
Acetate solvents:		
Crude	*P*	*P*
Pure	*P*	*P*
Acetic acid, glacial (1)	*G*	*P*
Acetic acid vapors	*G*	*P*
Acetic anhydride	*G*	*P*
Acetone	*G*	*P*
Acid mine waters	*G*	*G*
Alcohol: (2)		
Methyl	*G*	*F*
Ethyl	*G*	*F*
Propyl	*G*	*F*
Isopropyl	*G*	*F*

* Based on maximum temperature limits of 150°F unless otherwise stated. At temperatures from 150 to 210°F, the effects of oxidation, diffusion, and absorption are accelerated, and the life is shortened but in many cases is sufficient to justify the use of these linings, especially if oversheathed with suitable brick sheathing. Unless specific maximums are given, chemical concentrations are for any values up to saturation at atmospheric pressure. For low concentrations, from 0 to 5 per cent, it is generally preferable to use hard or semihard types of lining to prevent water soaking and surface effect. *G* = good; *F* = fair; *P* = poor; *IL* = information lacking.

† Number code for accompanying tabulation is as follows:

1. Discoloration and contamination is often a factor.
2. Plasticized polyvinyl chloride is classed as *F*, since some effect on plasticizer results especially at temperatures above 90°F: applies to all alcohols mentioned.
3. Very slight effect on plasticized polyvinyl chloride up to 90°F.
4. Very slight effect on plasticized polyvinyl chloride by 35 per cent at 90°F and by 10 per cent at 150°F.
5. Very slight effect on plasticized polyvinyl chloride by 35 per cent up to 130°F.
6. Plasticized polyvinyl chloride shows little effect up to 90°F with 90 per cent acid.
7. Very slight effect on plasticized polyvinyl chloride up to 90°F with concentrated acid, 22 per cent acid has little effect up to 140°F on plasticized polyvinyl chloride. Discoloration is often a factor. By-product acid with small amounts of organic impurities should be carefully checked.
8. Refers to 60 per cent maximum concentration—only slight effect on plasticized polyvinyl chloride at 90°F. Soft rubber recommended up to 50 per cent at 90°F.
9. Refers to 3 per cent maximum at room temperature. Plasticized polyvinyl chloride has been found satisfactory for use with 30 per cent hydrogen peroxide. Most other linings cause decomposition of 30 per cent concentration.
10. Applies to 70°F maximum.
11. Very little effect on plasticized polyvinyl chloride with 35 per cent at 90°F, with 20 per cent at 120°F and with 10 per cent at 150°F.
12. Refers to 85 per cent maximum. Contamination and discoloration is usually important.
13. Will handle most chrome-plating baths up to 25 per cent, chromic acid, 130°F maximum.

TABLE 1. CHEMICAL RESISTANCE OF LINING MATERIALS.—(*Continued*)

Substance†	*Rubber*	*Plasticized polyvinyl chloride*
Alcohol (*Continued*)		
Butyl	*G*	*F*
Isobutyl	*G*	*F*
Amyl	*G*	*F*
Alum:		
Ammonium	*G*	*G*
Chrome	*G*	*G*
Potassium	*G*	*G*
Sodium	*G*	*G*
Aluminum acetate	*G*	*IL*
Aluminum bromide	*G*	*G*
Aluminum chloride	*G*	*G*
Aluminum fluoride	*G*	*F*
Aluminum nitrate	*G*	*G*
Aluminum sulfate	*G*	*G*
Ammonium chloride	*G*	*G*
Ammonium hydroxide (3)	*G*	*F*
Ammonium persulfate	*G*	*IL*
Ammonium sulfate	*G*	*G*
Aniline hydrochloride	*G*	*IL*
Arsenic acid	*G*	*G*
Battery acid (sulfuric)	*G*	*G*
Beer (1)	*G*	*G*
Beet-sugar liquors	*G*	*IL*
"Black liquor" (3)	*G*	*F*
Bleach liquor (3)	*G*	*F*
Borax	*G*	*IL*
Boric acid	*G*	*IL*
Brine (calcium or sodium chloride)	*G*	*G*
Calcium bisulfite (10)	*G*	*F*
Calcium chloride	*G*	*G*
Calcium hypochlorite (3)	*G*	*F*
Cane-sugar liquors	*G*	*IL*
Carbolic acid (phenol)	*P*	*P*
Carbon disulfide	*P*	*P*
Carbon tetrachloride	*P*	*P*
Carbonic acid	*G*	*G*
Castor oil	*G*	*IL*
Caustic potash (4)	*G*	*F*
Caustic soda (4)	*G*	*F*
Chlorinated salt brine (3)	*G*	*F*
Chlorinated acid	*F*	*P*
Chlorine:		
Dry	*P*	*P*
Wet (3)	*G*	*F*
Water (3)	*G*	*F*

TABLE 1. CHEMICAL RESISTANCE OF LINING MATERIALS.—(*Continued*)

Substance†	*Rubber*	*Plasticized polyvinyl chloride*
Clorox	*G*	*G*
Chrome-plating solution	*P*	*G*
Chromic acid (5)	*P*	*F*
Citric acid	*G*	*IL*
Cocoanut oil (3) (10)	*G*	*F*
Copper chloride	*G*	*G*
Copper cyanide (in solution with alkali cyanides)	*G*	*G*
Copper sulfate	*G*	*G*
Cottonseed oil (3) (10)	*G*	*F*
Creosote, crude	*P*	*P*
Developing solutions	*G*	*G*
Epsom salts	*G*	*G*
Ethylene glycol	*G*	*IL*
Fatty acids	*F*	*IL*
Ferric chloride	*G*	*IL*
Ferric sulfate	*G*	*G*
Ferrous sulfate	*G*	*G*
Fluoboric acid	*G*	*G*
Fluosilicic acid	*G*	*G*
Formaldehyde, 40%	*G*	*IL*
Formic acid (6)	*G*	*F*
Fruit juices (1)	*G*	*IL*
Fumaric acid	*G*	*IL*
Gallic acid	*G*	*IL*
Glauber's salt	*G*	*G*
Glucose	*G*	*G*
Glue	*G*	*IL*
Glycerin; glycerol	*G*	*IL*
Hydrobromic acid	*G*	*IL*
Hydrochloric acid (7)	*G*	*F*
Hydrocyanic acid	*G*	*IL*
Hydrofluoric acid (8)	*F*	*F*
Hydrofluosilicic acid	*G*	*IL*
Hydrogen peroxide (9)	*G*	*G*
Hydrogen sulfide, wet	*G*	*IL*
Hydroquinone	*G*	*IL*
Hypo solution	*G*	*G*
Hypochlorous acid (3)	*G*	*F*
Lactic acid (1)	*G*	*IL*
Lead acetate	*G*	*IL*
Lead nitrate	*G*	*IL*
Lime bleach (3)	*G*	*F*

TABLE 1. CHEMICAL RESISTANCE OF LINING MATERIALS.—(*Continued*)

Substance†	*Rubber*	*Plasticized polyvinyl chloride*
Lime water	*G*	*G*
Lye solution (4)	*G*	*F*
Magnesium chloride	*G*	*G*
Magnesium hydroxide	*G*	*IL*
Magnesium sulfate	*G*	*G*
Maleic acid	*G*	*IL*
Maleic anhydride	*G*	*IL*
Mallic acid	*G*	*IL*
Mercuric chloride	*G*	*IL*
Mine water:		
Acid	*G*	*G*
Alkaline	*G*	*G*
Mineral oil (3) (10)	*G*	*F*
Muriatic acid (hydrochloric acid) (7)	*G*	*F*
Mustard	*G*	*IL*
Nickel acetate	*G*	*G*
Nickel chloride	*G*	*G*
Nickel nitrate	*G*	*G*
Nickel sulfate	*G*	*G*
Niter cake	*G*	*G*
Nitric acid (11):		
15° Bé, max. (10)	*G*	*G*
35% max (25.6°Bé)	*P*	*G*
Oleic acid	*F*	*IL*
Oxalic acid	*G*	*IL*
Palmitic acid	*F*	*IL*
Phosphoric acid (12)	*G*	*G*
Plating solutions:		
Brass	*G*	*G*
Cadmium	*G*	*G*
Chrome (13)	*P*	*G*
Copper:		
Acid	*G*	*G*
Cyanide	*G*	*G*
Gold	*G*	*G*
Indium	*G*	*G*
Lead	*G*	*G*
Nickel:		
Gray	*G*	*G*
Bright	*G*	*G*
Rhodium	*G*	*G*
Silver	*G*	*G*
Tin	*G*	*G*
Zinc	*G*	*G*

TABLE 1. CHEMICAL RESISTANCE OF LINING MATERIALS.—(*Continued*)

Substance†	*Rubber*	*Plasticized polyvinyl chloride*
Potassium acid sulfate	G	G
Potassium antimonate	G	G
Potassium bisulfite (10)	G	F
Potassium carbonate	G	G
Potassium chlorate	G	IL
Potassium chloride	G	G
Potassium cuprocyanide	G	G
Potassium cyanide	G	IL
Potassium hypochlorite (3)	G	F
Potassium phosphates	G	G
Potassium sodium tartrate	G	IL
Potassium sulfate	G	G
Potassium sulfite	G	G
Potassium thiosulfate	G	G
Pyroligneous acid	G	IL
Sal ammoniac	G	G
Salicylic acid	G	IL
Salt brine	G	G
Sea water	G	G
Soda ash (sodium carbonate)	G	G
Sodium salts (see potassium salts)	G	G
Sodium hydroxide (4)	G	F
Sodium perborate	G	IL
Sodium phosphate, tri-	G	G
Stannic chloride	G	G
Stannous chloride	G	G
Sugar solutions	G	IL
Sulfite liquors (3)	G	F
Sulfur dioxide water (3)	G	F
Sulfuric acid, 42° Bé max	G	G
Sulfurous acid (3)	G	F
Tannic acid	G	IL
Tartaric acid	G	IL
Triethanolamine	G	IL
Vegetable oils (3)	G	F
Vinegar (1) (3)	G	F
Water	G	G
White liquor (3)	G	F
Whisky and wines (1)	G	G
Zeolites	G	G
Zinc acetate	G	G
Zinc chloride	G	G
Zinc sulfate	G	G

Since PVC linings are not vulcanized, adhesives developed so far for applying such linings to tanks are all of room-setting composition and require no external heat. In general, this type of bond is not so resistant to elevated service temperatures as those set at high vulcanizing temperatures.

Before PVC or similar plastic material can be handled so as to permit installation as lining, it is modified by the addition of plasticizers. These plasticizers prevent the lining from developing its ultimate chemical resistance, because they are themselves not so chemically resistant as the base material. For example, bone-hard PVC will resist very strong solutions of nitric acid, but PVC tank linings will resist only up to 50 per cent nitric acid solution (equal parts of concentrated HNO_3 and water) at room temperature. As the temperature increases, the effect on the plasticizer will be more pronounced.

Polyvinyl-chloride lining characteristics are as follows:

1. Resists strong oxidizing acids such as chromic and nitric.
2. Is easily repaired when damaged.
3. Resists abrasion better than thin corrosionproof films.
4. Is superior to corrosion-resistant paints with respect to physical abuse and pinhole leaks.
5. Can be applied as thick as $\frac{3}{16}$ inch.
6. Leaks are easily located with an electric tester (see page 321).
7. Its electrical resistivity is high, making it efficient in preventing current loss in electrolytic actions.
8. Is highly resistant to water, sunlight, oxidation, and gas diffusion.

Limitations of PVC follow:

1. Is somewhat more costly than rubber linings.
2. Is unsuitable for use with chlorine-containing organic compounds such as ethylene dichloride, carbon tetrachloride, chloroform, dichlorobenzene, and monochlorobenzene.

MURIATIC ACID RESISTANCE. More rubber-lined equipment is used to handle muriatic acid than any other industrial chemical. This acid has some effect on all rubber compounds; but when it acts upon crude soft rubber, it forms a hard film on the rubber surface. This tends to prevent further acid diffusion into the rubber, and consequently the lining stands up for prolonged periods. Hard and semihard crude rubber withstand muriatic acid well, but it is not always possible to use them.

Muriatic acid penetrates Butyl and Neoprene and soft GR-S and soft Nitril rubber because the protective film is not formed with compounds of these materials. However, it is possible to vary the hardness of GR-S and Nitril rubber by the addition of sulfur, and the harder compositions

compare with crude rubber of similar hardness in resistance to muriatic acid.

SULFURIC ACID RESISTANCE (50 PER CENT MAXIMUM ACID CONCENTRATION). This acid is encountered most widely in the steel industry. Resistance of soft GR-S lining stocks is about equal to that of soft crude rubber. Soft rubber resists sulfuric acid better than it does muriatic.

PLATING SOLUTIONS. Both crude- and American-made rubber linings have been developed to meet the needs of the plating industry. They are compounded specifically to prevent contamination of the plating solution, which is an important factor in all plating installations. In general, the only plating solutions that rubber cannot be made to resist are those used for chromium plating. Plasticized PVC is not affected by chrome-plating baths and therefore can be used instead of rubber.

ELECTRICAL TESTING OF LINED METAL VESSELS. For testing a rubber or rubberlike plastic lining for leaks, a device resembling the familiar ultraviolet-ray machines may be used. The applicator is moved over the surface of the lining. Normally, there is a faint, bluish discharge that is evenly dispersed over the surface of the lining. When the applicator reaches or merely comes near a break in the rubber, even a pinhole that is virtually invisible, the discharge concentrates itself into a bright arc that passes with a distinct crackling sound through the lining to the metal beneath. The spark actually "points out" the defect to the inspector.

ASPECTS OF TANK DESIGN

Some of the facts that should be kept in mind when designing tanks to be lined with rubber are the following:

VERY LARGE TANKS. Often such vessels are made in sections that will go into existing vulcanizing autoclaves and later are assembled with rubber gaskets to seal the joints. Vulcanizers (cylindrical) 15 feet in diameter and 45 feet long are in use and will handle practically any lined equipment that can be shipped.

ACCESSIBILITY. Linings are placed on tank walls by hand, much as a paperhanger works on a room wall. Therefore all inside surfaces to be lined must be accessible. Because of high labor costs in relation to other costs, the design that requires a minimum of work is the most economical.

WELDED TANKS. Because of low cost and flexibility of design possible, most metal tanks intended for rubber lining are made by welding steel plates together. A rubber lining is easier to apply over a welded seam than over a riveted one.

Before being sent to the rubber-lining fabricator, a tank should meet the following specifications:

All sharp or irregular places should be removed. These might include weld spatter, burrs, porous spots, sharp-edged depressions or pits, sharp or rough edges of plates, sharp edges of nipple outlets, exposed threads of nipple flanges or pipe, and irregular weld bead.

Pits and porous places may cause blisters under rubber lining. It is permissible to remove porosity by peening.

All corners and edges should be given a radius of at least ⅛ inch.

Burrs, weld spatter, etc., are removed by grinding.

Nipple flanges may be welded or screwed flush with pipe end; if not welded, they should be peened to hold them tight.

Edges of all nipple outlets should be rounded.

Large tanks to be assembled in sections require matching flanges having bolt holes drilled before placing of the lining, which extends out over each flange.

The metal part of a tank must be tight and meet all pressure requirements before lining can be applied.

Manholes for entrance of workmen should have a minimum diameter of 18 inches.

Flanged type outlets are used. The lining extends out over the faces of the flanges.

Rubber lining reduces the inside diameter of nipples. Nipple sizes usually range from 1½ inches upward.

Castings. The same precautions about roughness, etc., apply to castings as to steel-plate parts. Gray iron having a close grain and freedom from porosity is essential. Inspection for porosity should be made after sandblasting. Sometimes bad spots can be drilled out and fitted with a threaded steel or iron plug. No other metal or iron cement material is satisfactory.

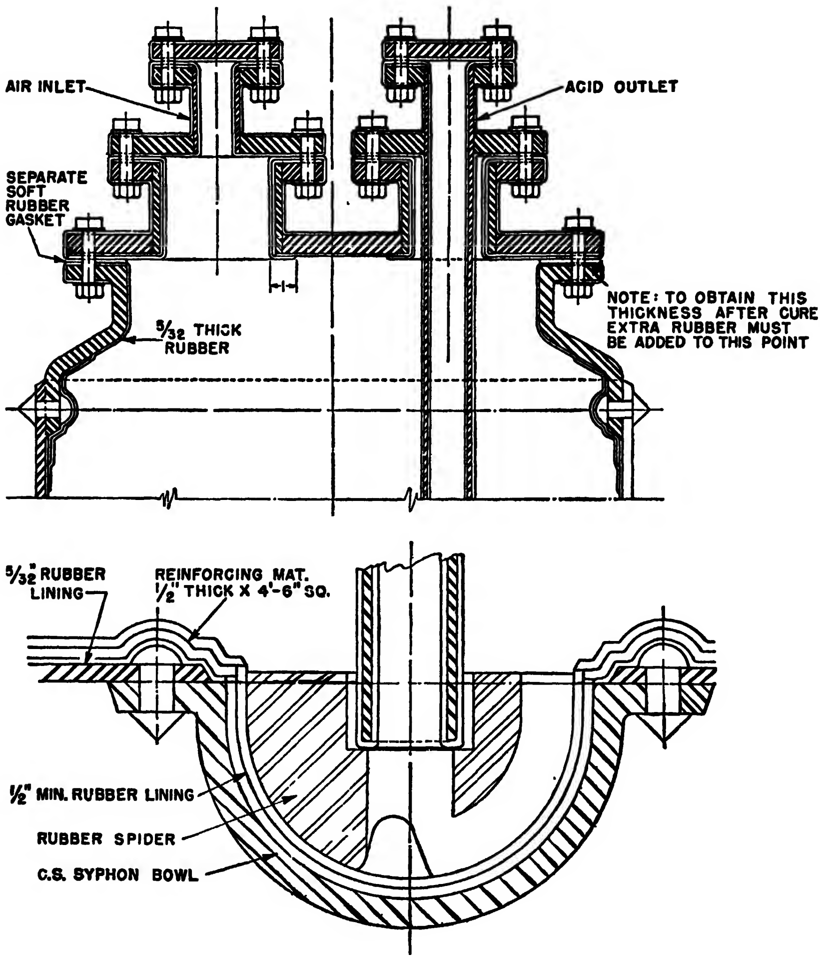
Riveted Tanks

Railway Tank Cars. Rubber-lined railway tank cars are used for transporting liquids including phosphoric acid, muriatic acid, formaldehyde, ferric chloride, pure caustic, and white pickling acids. Customary lining thickness is 3/16 inch, with an additional 3/16 inch over rivet heads and seams. Directly under the dome is placed a ½-inch rubber pad to prevent injury from measuring rods and dropped objects.

Preparation of Tank Cars for Lining. An old or new car must be accompanied by a certificate of construction as evidence that it complies with Interstate Commerce Commission Specification 103 B. This is

necessary because a certificate of construction covering the entire rubber-lined car must be furnished by the lining manufacturer to the Bureau of Explosives.

INSIDE FINISH. Surfaces must be free of pits, burrs, sharp edges, etc., as specified for welded tanks. All seams and rivets must be caulked tightly with round-nose tools. All rivets must be tight, and there must be no undercutting or deep grooves around rivets.



SECTION THRU SYPHON BOWL SHOWING RUBBER LINING & SPIDER

FIG. 2. Standard construction of a rubber-lined railway tank-car dome and sump bowl. The sump bowl provides support for the well pipe and prevents chattering and possible eventual crystallization and breaking of the pipe metal.

Old Cars. Often the cost of preparing an old car to meet lining requirements is excessive. However, many old cars have been lined and used for a number of years. If acid was transported in the car before lining, all traces must be removed by prolonged treatment with boiling water. Even after this precaution, blistering sometimes results from residual acid. However, such blistering can be repaired.

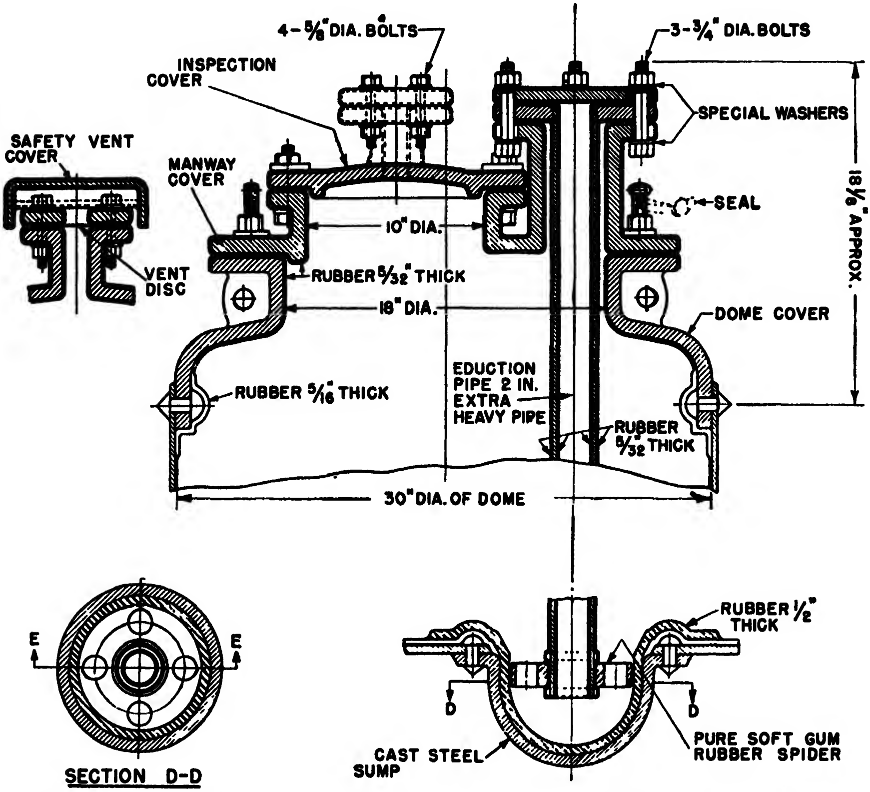


Fig. 3. Section through a rubber-lined railway tank-car dome and sump bowl of a type installed by a large manufacturer of tank cars.

Bottom Outlets. These are not permissible in railway tank cars.

Manhole. This should be 18 inches in diameter. Manhole covers and discharge fittings corresponding to those illustrated will prove satisfactory.

Special Tank-car Designs. These should be worked out in conjunction with engineers of the company that will apply the rubber lining.

Tank-car Service Precautions. To prevent undue damage to rubber linings, the following should be kept in mind: (1) Workmen

entering a lined tank should wear heavy cloth pads over their shoes and be careful when handling tools. (2) Gauge rods should have rubber tips, similar to those used on crutches. (3) Care should be exercised not to damage the rubber lining when removing fittings or dome cap. (4) Tools or other objects should not be allowed to drop into the tank through the dome. (5) Because water is injurious to linings, tank cars should be washed out only when absolutely necessary and water should be drained immediately and replaced with acid. (6) Unless the lining is designed for high-temperature service, hot acids should not be admitted to the car. (7) The lining should be protected from oils and greases, and nuts or bolts on cover, etc., lubricated only with a mixture of flake graphite and glycerin. (8) When flanges or other rubber-covered parts are being assembled, rubber surfaces that touch each other should be covered with flake graphite to prevent ultimate curing together. (9) Acids transported in rubber-lined tank cars should never contain traces of oils, gasoline, benzol, or other rubber solvents.

Protecting Rubber Linings

Pickling tanks and other containers subjected to rough physical abuse may be lined with boards or other materials to protect the rubber from

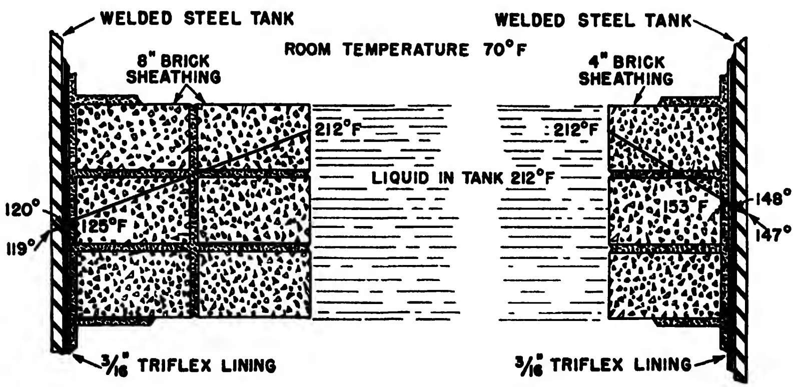


Fig. 4. Brick sheathing applied over the rubber lining of a tank acts as an insulator and protects the rubber from mechanical injury. The drawing shows temperature differentials for 4- and 8-inch sheathing.

injury. A widely used construction is to install one or more thicknesses of acidproof brick over the entire rubber-covered surface. The brick prevents mechanical damage to the rubber and acts as a thermal insulator to protect the rubber from excessive temperatures.

Pipe and Fittings

Rubber-lined pipes are used to transport acids and other chemicals, the rubber serving the same purpose as it does in tanks.

After the interior of the pipe is cleaned and coated with cement, an unvulcanized rubber tube is drawn through it and expanded against its sides by air pressure. Because of the difficulty of handling American-rubber materials in this way, crude-rubber linings are most practical.

Standard wrought-steel, wrought-iron, cast-iron, and spiral welded pipe are generally used.

Pipe Dimensions. The diameter is from 1¼ inches up. The length is in accordance with Table 2.

Table 2. Maximum Lengths of Pipe That Can Be Rubber-lined*

Size of pipe, in.	Length, ft		
	⅛-in. rubber	3/16-in. rubber	¼-in. rubber
1¼	20		
1½	20	12	12
2	20	12	12
2½	20	20	20
3	20	20	20
3½	20	20	20
4	20	20	20
5	20	20	20
6	20	20	20
8	20	20	20
10	20	20	20
12	20	20	20
14	20	20	20
16	20	20	20

* These figures do not apply for vacuum service, or for heavier than ¼ inch thickness lining; or for lining whose application is limited by the accessibility for rolling the rubber down.

Lining Thickness

	Inch
Minimum	⅛
Severe abrasive service on 2-in. and larger pipe	¼–½
Flange lining	⅛

Joining Sections. 1. Flanged joints. Flanges may be welded or screwed on pipe. Rubber lining is brought out over each flange, so when two flanges are bolted together, there is a rubber-to-rubber seal. When the lining is of a soft-rubber compound, it extends just to flange bolt

holes. Since each flange has ⅛ inch of rubber, total rubber thickness is ¼ inch. Two noncompressible asbestos gaskets each $\frac{3}{32}$ inch thick are placed between uncovered parts of flanges, limiting the degree of rubber compression to $\frac{1}{16}$ inch. When the lining is of hard rubber, it is extended over the entire flange face and a ring-type gasket of soft rubber used between the hard-rubber surfaces.

2. Plain-end pipe, as used with Flexlock coupling. Rubber is extended around the end and back over the outside surface for about 5 inches. The

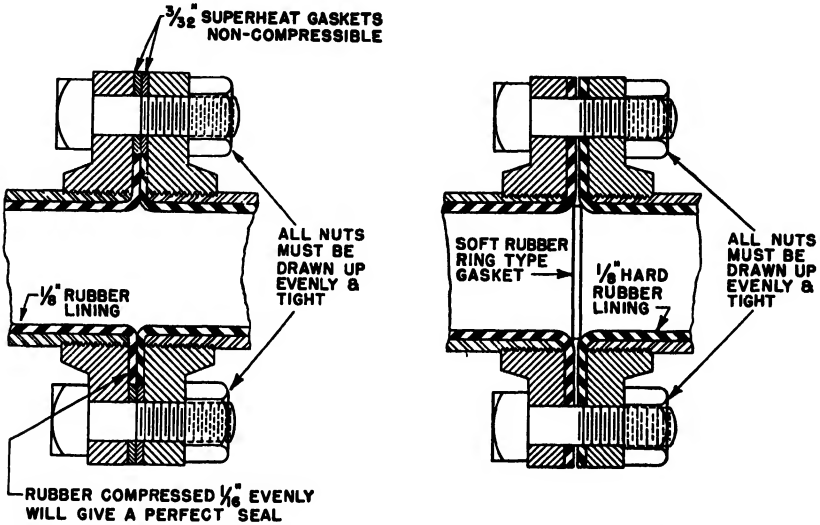
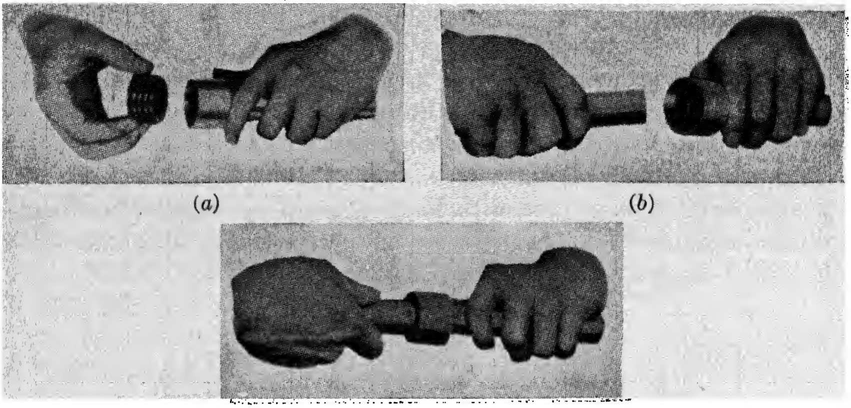


FIG. 5. Application of gaskets to flanged joints in rubber-lined pipe. The drawing at left shows a joint in pipe lined with soft rubber; the one at right, a joint in pipe lined with hard rubber.

joint is sealed with rubber-lined steel split sleeves and Flexlock gaskets. Such a joint is particularly adapted to gravity flow and low-pressure installations of rubber-lined pipe. The special Flexlock gasket is essentially a soft-rubber sleeve having internal and external ribs that, when compressed, grip the pipe ends and the sleeve tightly. A special cement applied to joined surfaces makes the seal virtually integral. This joint may be used in an open ditch, tunnel, or back-filled earth trench.

3. Rubber expansion joints, for use with flanged pipe that undergoes endwise expansion. One type consists of two steel rings between which is a soft-rubber ring bonded to the metal rings. A joint of this type will absorb up to ½ inch of compression or expansion, or a total movement of 1 inch. A modification involves the use of a steel ring around the outside circumference of the rubber ring to limit distortion when the joint is under compression.



(a) (b) (c)

Fig. 6. Assembling a small Flexlock coupling. (*a*) A rubber sleeve, with ribs inside and outside, is placed in the end of a pipe. (*b*) The end of a pipe of smaller diameter is pushed into the sleeve. (*c*). The resulting joint will resist a strong direct pull but can be separated by a twisting, unscrewing action. Typical dimensions for which these couplings are made are:

Inside Pipe (*O.D.*), *In.*	*Outside Pipe* (*I.D.*), *In.*
1	1 15/32
1 1/16	1 7/16
1 7/32	1 19/32
2	2 11/16
2 1/2	3 1/4
2 5/8	3 1/4
3	3 3/4
3 5/8	4 1/4
4	4 3/4

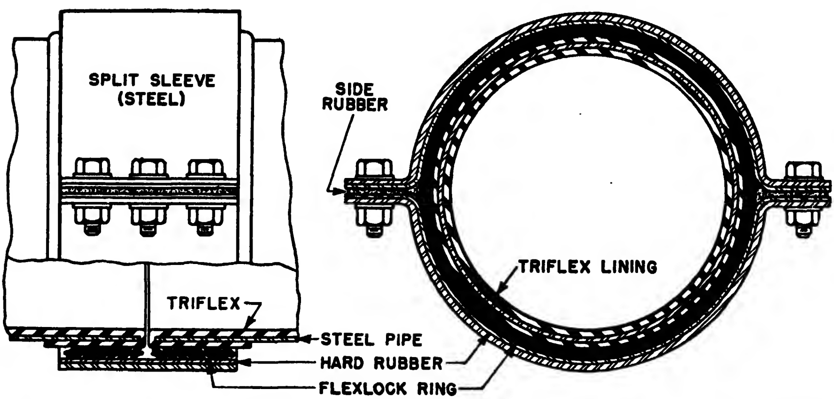


Fig. 7. The Flexlock coupling assembly. This split-sleeve pipe coupling consists of two low-pressure gaskets, two side rubbers, two half sleeves, and six bolts. Pipe and sleeves may be either steel or cast iron.

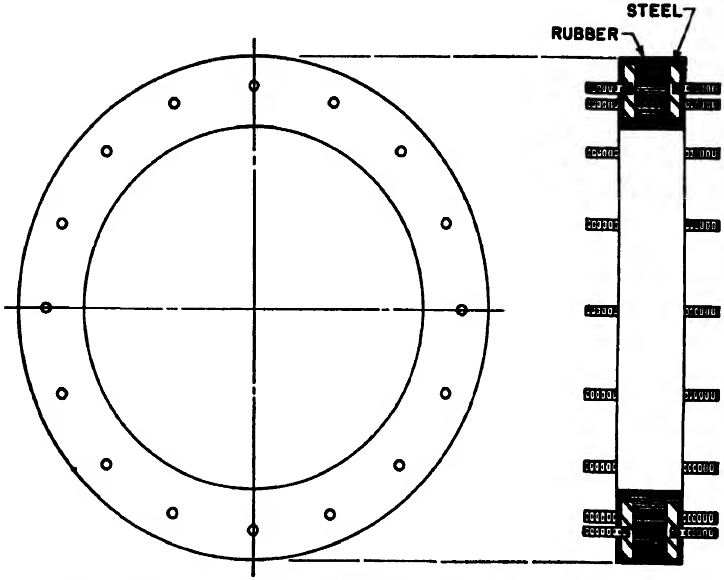


Fig. 8. Rubber expansion joints for pipe lines employ soft rubber as the sole joining medium. Each steel ring is provided with a series of stud bolts on a standard bolt circle, for attaching to flanges of the adjoining pipe lengths.

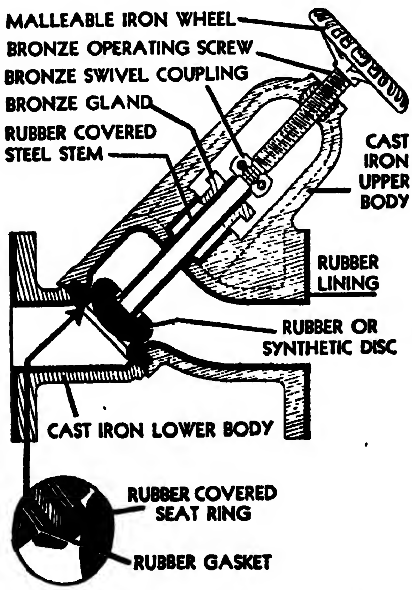
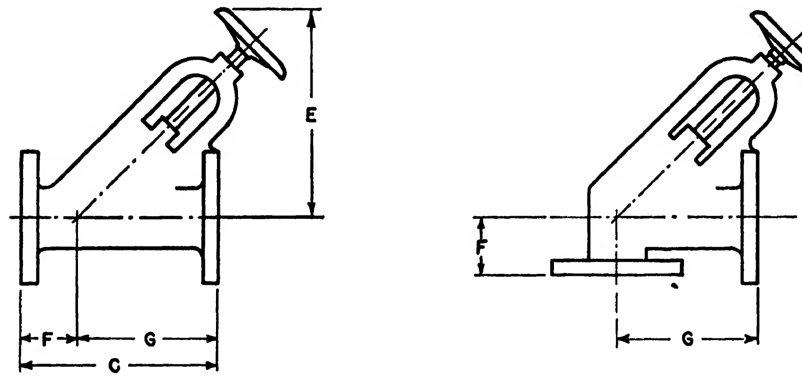


Fig. 9. A Vulcalock valve suitable for handling corrosive and abrasive fluids under fairly high pressure, pulsating pressure, throttling, or vacuum.

Some Uses of Rubber-lined Pipe. Such pipe is used for carrying the following:

Purified water
Acids such as acetic, phosphoric, muriatic, sulfuric
Powdered coal
Flue gas wash water
Mill tailings
Mine water
Paper-mill pulp and bleach liquids
Sand and gravel in dredge work
Waste acids in steel plants
Ferric chloride or wet chlorine solutions



Nominal size	*Actual size* (*)	*Opening at seat*	*C*	*E*	*F*	*G*	*Approximate shipping weight*
1½	1¼	1⅜	7¼	7 9/16	2½	4¾	22 lb
2	1¾	1¾	8¼	10 5/16	2⅝	5⅞	31 lb
3	2¾	2¾	10¼	14¼	3¼	7	60 lb
4	3¾	3¾	14¼	17⅞	4 1/16	10 3/16	116 lb
6	5¾	5¾	20¼	22⅝	5⅝	14⅝	223 lb
8	7⅝	7½	25¼	30⅞	5 11/16	19 9/16	340 lb

* Measured inside rubber lining.

Fig. 10. Dimensions of Vulcalock valves.

Valves. Valves used with rubber-lined pipe are designed so that liquid being handled comes into contact only with rubber. A typical valve suitable for either pressure or vacuum service is illustrated.

Valves having renewable rubber linings, as contrasted to those in which the lining is bonded to the metal, are also available.

Lined Pipe Design. Because of the fact that a rubber-lined pipe cannot be cut to length after lining, each installation has to be planned in detail beforehand. Usually the flanged type of pipe will be found best suited for all jobs except those involving large pipe diameters and gravity

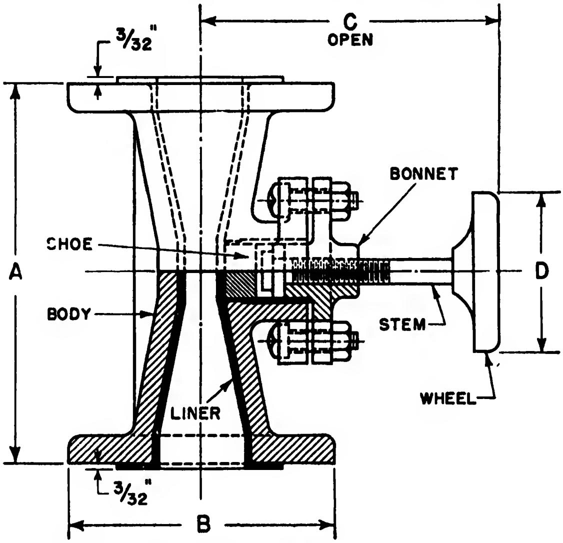


Fig. 11. A rubber-lined valve whose lining can be renewed. Important dimensions are as follows:

Valve size	Dimensions, in.						
	1	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3	4	6
(*A*). Over-all length	5	7	8	9	10	14	20
(*B*). Diameter of flange	4	5	6	7	$7\frac{1}{2}$	9	11
(*C*). Center to top of stem	$4\frac{3}{4}$	$5\frac{3}{8}$	6	$6\frac{1}{2}$	7	$7\frac{5}{8}$	13
(*D*). Diameter of wheel	$2\frac{3}{4}$	3	4	$4\frac{1}{2}$	$4\frac{1}{2}$	8	12
Center to center of bolt holes	3	$3\frac{7}{8}$	$4\frac{3}{4}$	$5\frac{1}{2}$	6	$7\frac{1}{2}$	$9\frac{1}{2}$
Diameter of bolts	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{3}{4}$
Number of bolt holes	4	4	4	4	4	8	8
Inside diameter	$\frac{55}{64}$	$1\frac{27}{64}$	$1\frac{53}{64}$	$2\frac{7}{32}$	$2\frac{3}{4}$	$3\frac{47}{64}$	$5\frac{11}{16}$

or low-pressure flows, where Flexlock joints may be preferred. As in so many other kinds of work involving rubber, the engineer intending to install a rubber-lined pipe system will find it desirable to submit his plans to a manufacturer of rubber-lined equipment. These plans may be in the form of drawings showing all essential details and dimensions of the system. The rubber manufacturer then can prepare detailed specifi-

cations, giving such information as the lining characteristics, rubber allowance at joints, expansion provisions required, and costs.

Barrels and Drums

Barrels and drums for transportation of acids and other liquids are made with rubber linings like those of tanks. There are two general types:

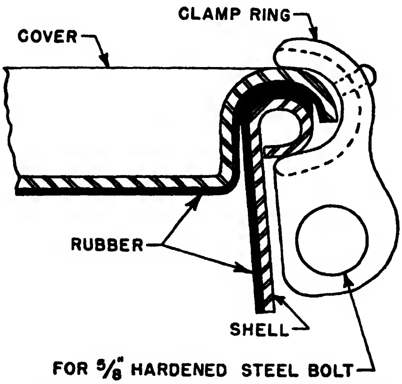


Fig. 12. Section through a rubber-lined barrel and head showing how rubber-to-rubber contact is obtained.

(1) seamless steel barrel with removable head. Barrel and head linings extend out over edges in such a way that they form a leakproof seal when head is clamped in place. (2) Steel drums with nonremovable heads and outlet in side. Outlet plug, when reversed, serves as a discharge spout.

Table 3. Typical Dimensions of Rubber-lined Barrels and Drums

	Height or length, in.	*O.D., in.*	*Tare weight, lb*
Barrels:			
30-gal.	28¼	20⅛	68
50-gal.	32¾	24⅛	118
Drums:			
50-gal.	35½	26	128

Repairing Rubber Linings

When a rubber lining becomes punctured, the damage caused by leaking acid or other chemical is confined to a small area, provided the adhesion between rubber and metal is good. The damaged spot can be

located easily, and repairs readily made. Repairs to tank-car linings may be made either in the field or in the factory of the company that installed the lining. Such repairing should be done by a man skilled in the work.

Rubber Armor

There are many applications of rubber in the form of an armor or "outside lining." Typical of such material is Armorite, a tough crude-rubber material developed to resist abrasion. It is a soft, black, elastic rubber having a tensile strength of about 4,000 psi. It is made in various forms, such as fabric-fiber base, fabric base, all-rubber, and steel base. Steel pipe lined with Armorite is used for carrying abrasive materials.

Applications. Armorite is used for covering such products as

Chutes and hoppers handling ore, sand, gravel.

Agitator bars used in mixing powdered aluminum oxide and silicon carbide in abrasive manufacture.

Impellers for flotation work.

Fan housings, fan blades, collectors for handling abrasive dusts.

Dredge pump liners.

Centrifugal pump linings.

Sandblast cabinets.

Armorite Construction. *All-rubber.* This form has thin open-mesh fabric on the back. It is used where maximum abrasive resistance is desired.

Fabric-fiber Base. Thicknesses are usually ¼, ⅜, and ½ inch. The dimensions of standard sheets are 4 by 50 feet. This type is suitable for most general abrasion-resistance service. It has two plies of heavy duck separated by a tough fibrous layer and may be attached with bolts, screws, nails, cement, or mastic tar. The average bolt spacing is on 12-inch centers.

Fabric Base. The same specifications apply as for fabric-fiber base, except that fibrous compound is omitted. This type is available with either one or two plies of fabric.

Steel Base. In this type, Armorite is attached to sheet steel by the Vulcalock process. Normal sheet size is 4 by 8 feet. Steel gauge is 10, 12, 14, 16. Maximum sheet sizes are as follows: up to 4 feet wide, 13 feet long; 4 to 5 feet wide, 12 feet.

Limitations. The service is limited to blows that rubber thickness can withstand. There should be no contact with oils. The temperature limit is 150°F. Armorite will resist mild corrosives, provided fabric plies are sealed along exposed edges.

Armorite may be applied to irregular shapes that permit workmen to install the uncured material by hand.

Chapter 16

MOLDED RUBBER

Most of the crude and American-made rubber and rubberlike plastics consumed today are converted into useful articles by molding. Three molding processes are in general use:

1. Compression molding, used for making nearly all crude- and American-made rubber molded goods. Used also for rubberlike plastics such as polyvinyl chloride compounds.
2. Injection molding, in which the compound is forced by pressure into the mold cavities, which may be relatively cold. The preferable method for thermoplastics.
3. Transfer molding, which is, in some respects, a cross between processes 1 and 2.

Compression Molding

Briefly, the process of making a compression-molded article of crude or American rubber is as follows:

1. The basic hydrocarbon (crude rubber, etc.) is mixed with antioxidants, age resistors, sulfur, pigments, and other ingredients to form a compound that has the desired characteristics for molding and that will produce other desired characteristics in the finished product. After thorough mixing, the compound is formed into easily handled pieces of suitable shape and made ready for introduction into the mold cavities.
2. The compound is introduced into the mold and subjected to heat and pressure for a period of time. During this period, vulcanization takes place, converting the doughy mass into a tough material.
3. The article is removed from its mold cavity and then is processed to eliminate any rind or flash that may be present. (Rind on a molded rubber article is comparable to the flash on a molded metal article and is caused by the escaping of excess compound from the mold cavity.)

Molded rubber products number into the thousands, but here are a few that will serve as typical examples: pump valves and diaphragms, mallet heads, grommets, vibration-absorbing units, grease seals (of oil-

proof compound), spring shackle bushings, dust masks, handle grips, pedal pads, bulbs, balls, electrical-equipment parts, electric sockets and other parts having metal inserts, gaskets, hot-water bottles, tires, corks, shoe heels, and bumper pads.

MOLDS. These usually consist of two or more flat metal plates of varying thicknesses, which are shaped so that when together, they form

FIG. 1. This collection of rubber parts shows the variety of shapes that can be produced by molding.

one or more closed mold cavities. Single molds having more than 1,000 cavities are in use.

PRESSES. After being charged with rubber compound, the molds are placed between the platens of hydraulic presses that apply both pressure and heat.

PRESSURE. The total pressure on the platens of a molding press may reach such magnitudes as 200 tons. For molding sponge-rubber articles, a press-ram pressure of 400 psi is used. For denser rubber compounds,

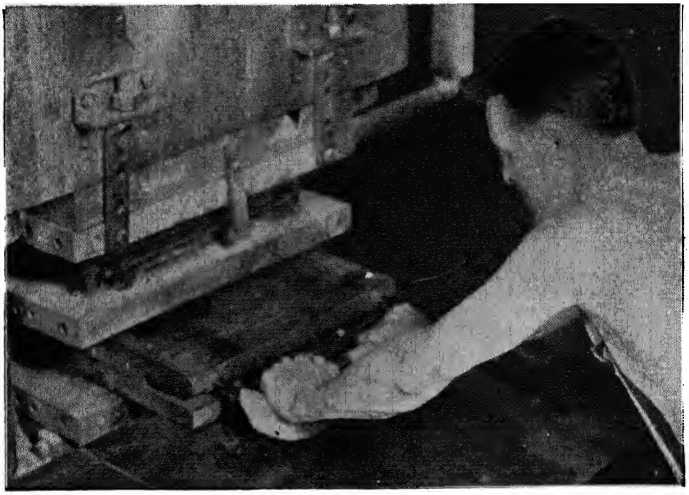


FIG. 2. Removing a two-part rubber mold from the heated platens of a molding press.

the ram pressure is around 1,500 psi. Thus a 10-inch ram at 1,500 psi would exert a total load of about 60 tons on the molding press platens and on the molds. Such great pressures constitute one reason why improper mold design may lead to trouble.

HEAT. The press platens usually are heated by steam, and this heat is transferred to the molds and their contents. Molding temperature varies with the compound and usually ranges upward from the temperature of boiling water (212°F).

Designing and Making Molds

Manufacturers of molded rubber goods maintain design departments and machine shops where molds are made. Outside the rubber industry, there are shops whose skill in making molds is equal to that of the rubber manufacturers, and rubber companies often subcontract mold work to such concerns.

Price and quality of a molded product are often determined by the design of the mold, which is the reason rubber manufacturers must employ competent design engineers familiar with all phases of rubber production.

One time a company that had been turning out high-class molds for rubber for years found that it needed some special molded rubber articles. It worked out a design, spent considerable money making a mold, and sent it to a rubber manufacturer for use in producing the molded pieces. But the mold would not work satisfactorily because adequate allowance had not been made for shrinkage of the rubber. Although accustomed to making excellent molds when guided by blueprints of skilled designers, the company had failed to do a satisfactory design job itself.

Other mold manufacturers faced with a similar problem have found that the price of a product was increased because they had not consulted a rubber manufacturer regarding such design factors as the placement of cavities and the operations to be used for finishing the product after molding.

Molds for rubber articles are costly because of the peculiar design and manufacturing problems involved and because they must be rugged enough to withstand the handling they will experience. It is in an effort to reduce such costs that inexperienced mold designers and makers often attempt to turn out rubber-molding equipment. In the long run, the least costly way is to follow one of the following courses:

1. Tell the rubber manufacturer in detail just what you want in the way of a molded product, and let him take care of the designing and mold making. Usually such designing costs are not charged against the customer.

2. Let a competent engineer work out the mold design, and then make the mold yourself, being certain that you follow the designer's blueprints no matter how silly some of the details may look to you. Or if you have your favorite mold shop do the job, insist that the design be followed faithfully.

3. Work out the mold design yourself; then submit it for checking and correcting to the manufacturer who is to mold the parts. Then let him make the molds, make them yourself, or give the job to an experienced mold shop.

Some Aspects of Mold Design

Designing and constructing a successful mold for rubber articles involve numerous factors that add up to make the project a complex one. Some of these factors, such as the polishing of mold cavities, are steps

that can be handled with maximum efficiency only by men whose skill is the result of long practice.

MOLD MATERIALS. Most molds for rubber are made of steel. The metal should be close-grained and of uniform, fault-free texture. A carbon content of 0.25 to 0.45 per cent is preferable.

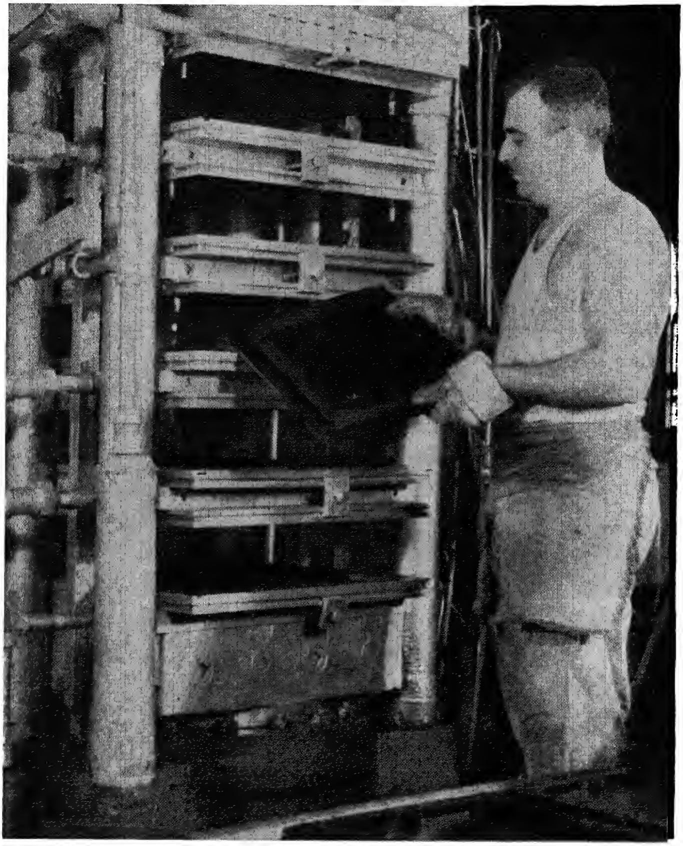


FIG. 3. This multiple-deck vulcanizing press handles five molds at once.

Molds are sometimes made of aluminum alloys or manganese bronze. Aluminum with a high silicon content is used for making molds by a special high-pressure process in which the alloy is compacted into a die. Molds difficult to machine by conventional methods can be made in this way.

Molds made of aluminum should be constructed so the pressure between plates is borne, not by the aluminum, but by steel-to-steel bearing surfaces. Lands made only of aluminum will sometimes squeeze out under heavy molding pressures.

Mold Dimensions. Molding presses have definite platen dimensions, and therefore the over-all sizes of rubber molds that a factory can handle are limited by the sizes of the presses. In some plants, it has been found uneconomical to use presses having platens smaller than 24 by 24 inches. Other typical sizes are 30 by 30 inches, 32 by 72 inches, and 22 by 124 inches. More than one mold can be handled at a time in multiple-deck presses, the molds being placed one above the other.

The size of the mold limits the number of cavities that can be cut in it. In a typical 24- by 24-inch mold, the cavities may cover 22 by 22 inches. Whenever possible, molds should be the same size as the platens. When the molds are smaller, the platens are likely to be damaged by bending. In no case should a single-cavity mold be less than 6 by 6 inches, and it preferably should be larger. Sometimes side plates are welded to small molds to prevent platen springing.

There have been instances where a mold, after being completed and sent to a manufacturer, was found to be too large to go into any molding press available. Simply stating that a press is "a 24- by 24-inch size" does not tell the whole story. There may be guide members or other parts that would interfere with hinges, handles, and similar protuberances projecting too far from an otherwise properly sized mold. The mold designer, therefore, should know something about the press in which the molding will be done before he can be certain of making a mold that will fit.

Rubber manufacturers have found that a poorly designed mold is often too flimsy for the long period of satisfactory service expected of it. Usually the plates making up the mold are too thin, and the cavities placed too closely together. Plate thickness should never be less than $\frac{3}{8}$ inch at the thinnest part, *i.e.*, measured from the bottom of the deepest cavity to the back of the plate. Top plates should be at least $1\frac{1}{16}$ inch thick so dowels and locating pins will remain firm. Thickness of mold plates is related to the position of the cavities: When the long cavity axis is perpendicular to the plate surfaces, maximum thickness is required.

Cavity Design. The proper positioning and spacing of cavities in a mold is a matter calling for considerable skill and experience. A mistake often made is to place cavities too closely together. Plenty of space (lands) between cavities is needed to prevent buckling of plates and provide room for rind cavities. This space should be from $\frac{3}{8}$ to 1 inch, the exact width depending on size and shape of the molded article.

After a mold cavity has been machined, it should be polished to remove all tool marks. Such polishing should be specified on the design, or the moldmaker may not produce the polish that the product requires.

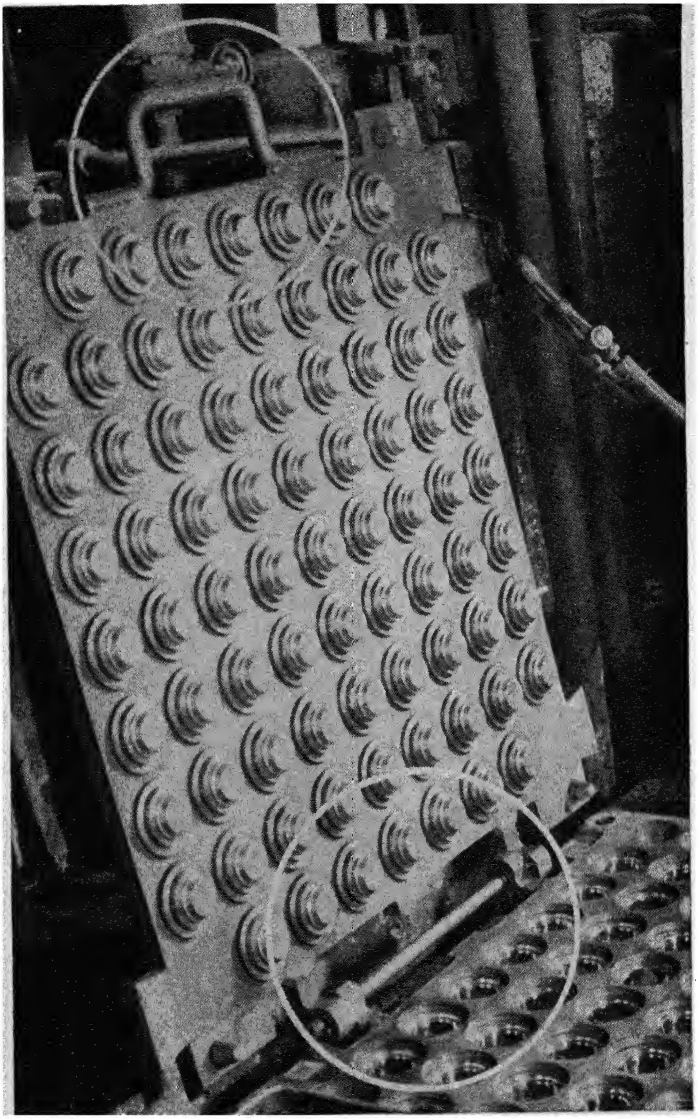


Fig. 4. A multiple-cavity rubber mold showing rugged hinge (*bottom circle*) and handle (*top circle*) that facilitate handling, speed production, and increase safety. For large, heavy molds, a handle that is an integral part of the plate is preferable to one attached by welding.

The polishing operation does not disturb dimensional tolerances, for at the most only a little more than 0.001 inch of metal is removed. For producing rubber articles having a mirror luster, it used to be the practice to chromium-plate cavities. However, such plating is likely to give trouble from peeling. The preferred method, when a very high gloss is desired, is to make the mold of stainless steel, which can be polished easily to a mirror finish. A similar high finish can be produced on molds made of ordinary steel but only at the expense of much greater time and effort.

RIND CAVITIES. In compression molding, the rubber stock is extruded and cut into definite lengths or formed into a slab and cut into blanks to produce pieces having a volume slightly greater than that of the finished product. Rubber is incompressible, so that during the molding process the slight excess in volume has to go somewhere outside the main cavity. Therefore it is necessary to provide auxiliary or rind cavities. Such a space is essentially a shallow groove running around the cavity and separated from it by a flash ridge. During the molding operation, resistance of the excess compound as it flows past this ridge creates pressure that forces the rubber into all parts of the cavity. The ideal condition is to have excess rubber not quite sufficient to fill the rind cavity; when there is not enough stock to flow into this cavity at all, the molded article will not be completely filled out.

The normal minimum width of the flash ridge between the main and rind cavities is 1/64 inch. It may range upward to 1/8 inch or more.

In some molds, the excess compound escapes upward, around telescoping parts of the mold plates.

Making the rind cavities should, preferably, be done by the manufacturer who will use the mold in producing rubber articles.

PARTING LINES. There may be several ways in which the parting line of a mold may be placed in producing a certain article, but usually there is only one "best" way. A rubber manufacturer, in order to produce a molded article that will be most economical, should have complete freedom of the parting line. The best way of assuring this is for his men to design the mold.

The parting line must be placed so as to facilitate removal of the article from the mold. Sometimes it is possible to make a certain piece in a two-plate mold, but only with considerable effort and waste because of the difficulty of removal. By using a three-plate mold, the job becomes an easy one. Parting lines must be placed so air will not be trapped in mold cavities and so the flash can be trimmed economically from the molded piece.

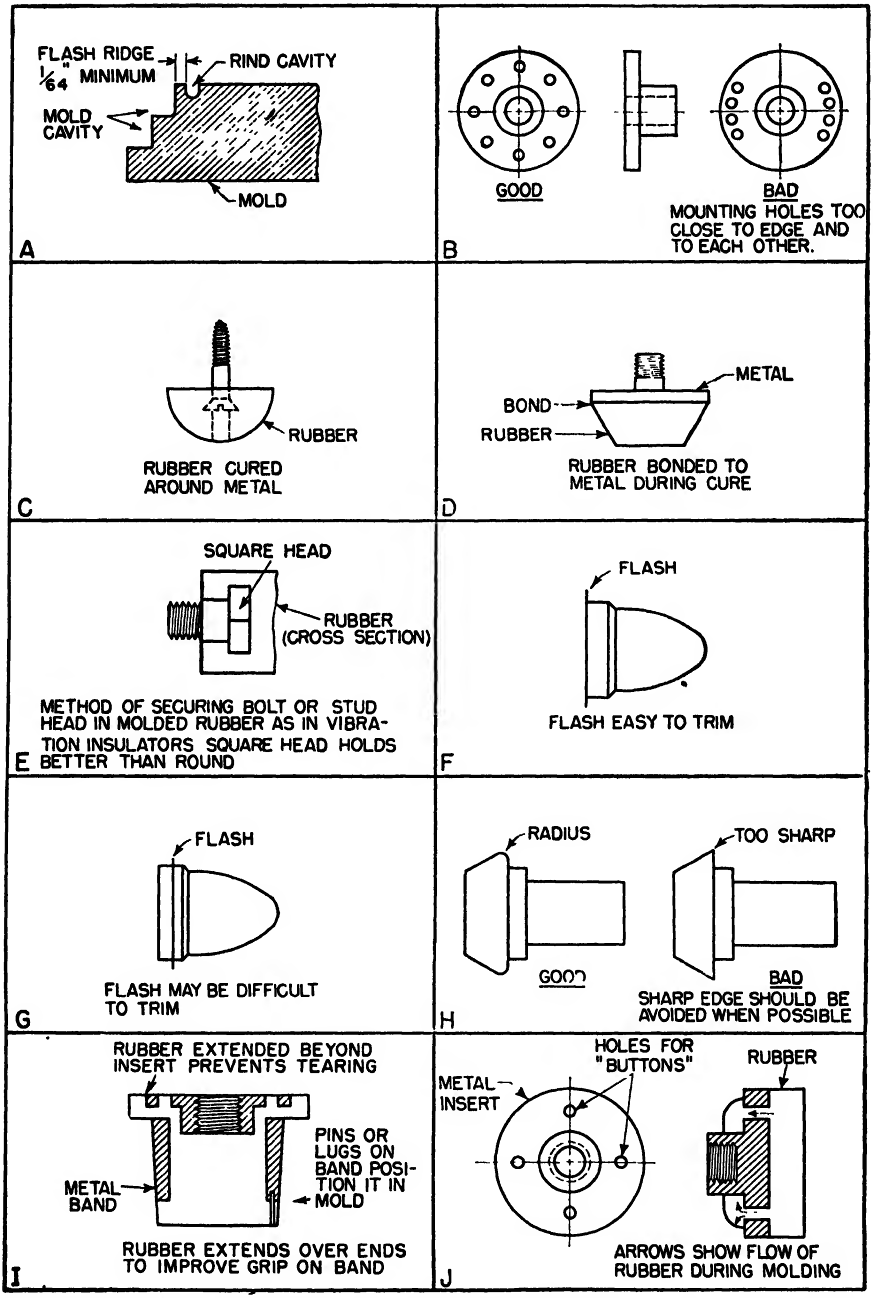


FIG. 5. Some factors involved in the design of molded rubber products. (*A*) Section through a mold showing the flash ridge and rind cavity, which are provided to take

Flash or Rind Size. In order to plan the mold properly, the designer must know how the product is to be finished after molding. One of the greatest problems in production molding is removal of the flash or rind formed of excess compound. Removal methods include

1. Die trimming, in which dies are used to cut the rind from around the piece. This method requires a mold designed to produce a heavy rind.

2. Burring. The flash or rind is removed by holding the article against a rotating abrasive stone of suitable shape. Thus, a cone-shaped stone may be used for removing flash from the edge of the hole in a tubular piece. The rind should be thin.

3. Tumbling. The finished parts are placed in tumbling barrels along with abrasive blocks, and the friction removes the rind, which should be molded thin. Though economical, tumbling has the disadvantage of slightly rounding all edges and altering dimensions and surface finish.

Fig. 6. An accurate, uniform product is assured by proper use of overflow or rind cavities into which excess rubber can flow (see Fig. 5*A*). The workman is about to tear the rind from a molded ring.

Mold Register. The plates of a mold must be brought together so the cavities in one piece are in register with the cavities or projections in the facing piece. This is accomplished by installing dowel pins in one piece, usually the top plate, which engage bushed holes in the other piece, usually the bottom plate. For a production mold, the dowels should meet the following specifications:

1. No less than four dowel pins should be used for each mold.

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care of excess rubber volume. (*B*) When possible, bolt holes and other holes in a molded product should be evenly spaced and not too near edges. (*C*) This rubber-headed screw is a typical product involving the molding of rubber around metal. (*D*) Here the rubber has been bonded to a metal surface during the vulcanizing period. (*E*) When rubber must resist the turning action of a bolt head embedded in it, the head should be square or some other shape that will not break loose easily. (*F*) The flash on this molded part is easy to trim off because it is along an outer edge. (*G*) When the flash is in an area between edges or in a concave portion, it is difficult to trim. (*H*) Good design calls for avoidance of thin, sharp edges. (*I*) This shows good relation of a metal insert and a metal band to rubber in a molded product. Rubber extends beyond the insert to hold it more securely and through several holes that help prevent the insert from twisting loose when the threads (which also hold insert in mold cavity) are used. (*J*) To provide a means of anchoring, rubber flows through holes in a metal part during molding.

2. Dowels should be a minimum of 7/8 inch in diameter.

3. Both dowels and bushings should be made of tool steel and should be hardened but not drawn.

4. Dowels should be staggered so the mold will go together in only one way. Otherwise, the mold may be ruined by improper assembly.

HINGES AND HANDLES. When the parts of a mold are hinged together, there is less chance for improper register, and handling of the mold is made easier and speedier. The hinge should be rugged and designed for the severe service it will encounter. Inexperienced mold builders sometimes install ordinary door hinges, which are much too flimsy. Hinged molds should contain dowel register pins.

FIG. 7. When a high finish is desired on a molded rubber product, mold cavities must be highly polished, as these are.

Handles on heavy production molds should be integral parts of the plates. Welded-on handles may come loose and cause serious injury to workmen and damage to the mold. Lighter molds may have handles made from bar steel and welded to the plates. Handles must be placed so they are not subjected to pressure in the molding press.

PRODDER LUGS. To facilitate safe opening of molds, the design should provide for prodder lugs. It is less costly to undercut plate corners so the prodder can be inserted, but this does not make it easy to open the mold, and a slipping prodder may cause injury to workmen.

DISSIMILAR METALS. Sometimes a mold having a steel male member and a female insert made of aluminum is used for rubber. Such an arrangement is likely to give trouble because of the binding tendency between the dissimilar metals. Such molds should be made entirely of one metal.

MOLDING SPONGE RUBBER. Articles such as the cushions for arm rests used on automobile doors are molded from sponge rubber. The designing of a mold for sponge is an art considerably different from that of designing for solid-rubber products. Single-cavity molds for sponge rubber should be of the male-female type in order to give better register. A press used for sponge molding operates on a lower ram pressure than one handling solid rubber, usually about one-fourth as much; lower pressures are used to facilitate bleeding of air from the mold cavities. A method has been perfected for molding a solid rubber cover on a sponge core. Thus a sponge-rubber article having a smooth, water-repelling

cover can be produced in a single molding operation. Molds for such purpose have to be designed throughout by the rubber manufacturer who is to perform the molding.

SPONGE-RUBBER MOLD COMPLEXITY. In the molding of chemically blown sponge rubber, the volume of the compound placed in each cavity is less than the cavity volume—in contrast to solid rubber whose volume is slightly greater. The sponge compound resembles bread dough in that it contains a rising agent, usually sodium bicarbonate. This decomposes under heat of vulcanization to form bubbles of carbon dioxide gas, which expand and cause the rubber to fill the cavity. The expanding pressure is extremely low compared with that used in the molding of solid rubber.

Because of the low level of pressure, the complexity of a sponge-rubber mold is limited. Designers of sponge-rubber parts should strive to keep them as simple in form as possible. Thin fins or other projections extending from the main body should be avoided, for it is difficult to produce flowing of the sponge compound from the main mold cavity into narrow lateral cavities; and when a section of any kind is too thin, the spongy nature of the material causes weakness and tendency to tear.

Not all the gas bubbles formed in the sponge compound contribute to expansion of the mass. Many of those near the surfaces not in contact with the mold cavity escape and, by accumulating in the unfilled parts of the cavity, build up a back pressure that, if unrelieved, would prevent the material from filling the mold. Therefore vent holes have to be drilled to bleed off the accumulated gas and air. The placing of these vents for the best effect involves considerable skill. Molds for solid rubber often require venting too.

TOLERANCES IN MOLDED PRODUCTS. There is no standard tolerance for any rubber product, because stocks vary so widely. The standard range for solid-rubber compounds, however, is from about 0.010 to 0.025 inch plus or minus. For sponge rubber the range is 0.010 to 0.060 inch plus or minus, the exact figures depending on the size of the section.

RUBBER SHRINKAGE. A molded rubber article shrinks as it cools, after curing. The average rate of shrinkage is 0.016 inch per inch.

TOLERANCES IN MOLDS. An experienced mold designer knows just how much tolerance should be allowed for different dimensions of a piece. The normal tolerance on production molds is ± 0.005 inch. For precision molding jobs, the tolerance is ± 0.002 inch. Fractional tolerance on production molds is $\frac{1}{10}$ inch. On thickness of molded pieces, the tolerance should preferably be taken all on the plus side to allow a little extra rind.

Rubber-mold makers are qualified by training and experience to determine just what degree of precision to use. These men, who are truly

artists as well as being capable machinists, are on a par with high-class diemakers. Among other accomplishments, they are skilled at engraving letters, trade-marks, and other designs on molds, and they can produce shaded designs that, in the molded article, exhibit effects similar to that of changeable silk. Such skill is, of course, involved in the matter of determining mold cost. Seldom do "bargain molds" made by inexperienced rubber-mold craftsmen exhibit the influence of equivalent artisanship. A poorly made mold, like a badly designed one, often costs more in the end than one made by the best skill available, for it generally has to be repaired or rebuilt—or thrown away entirely without a single acceptable product having been molded in it.

Mold Costs. Practices may vary with individual companies, but in general the following conditions apply:

The customer pays for actual labor, material, and shop cost involved in making a mold to meet his requirements when the rubber manufacturer does the work.

The customer is not charged for any mold-design work performed by the rubber manufacturer, although such work may run into considerable money.

When a mold made "outside" is unsuitable for use when received by the rubber company or is found so after a test run, the customer is asked to authorize repair or perhaps complete redesigning and rebuilding. Actual labor and shop costs are charged to the customer.

Prices for rubber molds do not vary greatly in different sections of the country.

Molds kept on hand by the rubber manufacturer for future runs are normally stored and kept in working condition at no cost to the customer.

When a mold has become so worn with use that it is no longer serviceable, the customer pays for the making of a new one.

Metal Inserts. An insert made of stamped or cast metal is involved in the molding of various products such as electrical parts. Mold and insert have to be designed so the latter will be held securely in position while the rubber compound is being compressed and cured around it or bonded to one or more of its surfaces. Some articles require an insert that, in the finished product, will be entirely surrounded by rubber. Floating inserts have been employed in such production, but they are seldom entirely satisfactory because of their tendency to move about in the mold cavity. Sometimes a tough production problem on a piece having an enclosed insert can be solved by semicuring halves or other sections of the article, assembling them around the insert, and then finishing the cure in a mold; the partly vulcanized compound holds the insert in place during the final cure.

Molded rubber is united with metal inserts in the following ways:

1. Use of adhesives between metal and rubber.
2. Sandblasting of metal surface to produce rough texture to which rubber will adhere.
3. Brass-plating metal surface where adhesion is desired or using solid-brass insert.
4. Forming holes in metal piece so rubber compound will "button through." This arrangement is used when insert is to be held in position by rubber but rubber-to-metal adhesion is not desired.

Inserts have to be machined or stamped to definite sizes to enable them to fit the mold cavities. Tolerances in dimensions depend upon shape and size of the insert, but the average over-all margin is around 0.014 inch.

CLOTH INSERTS. Cotton fabric ranks with metal as an insert material. It is superior to wool, which deteriorates at high curing temperatures. Synthetic fabrics such as Nylon may be used.

VOLUMETRIC (INJECTION) MOLDING

This type of molding has been applied successfully to the production of crude- and American-rubber articles, but it is more applicable to the making of complicated small shapes from plasticized polyvinyl chloride and similar elastomers. When a rubber article, because of its nature or shape, cannot be molded by conventional means, volumetric methods may provide a way out. Parts made entirely of rubber or of rubber and metal can be molded by injection. Generally the finish is better, tolerances are held more closely, and less rind is produced than when compression molding is used. Among rubber products that can be molded volumetrically are boots and milking-machine inflations.

MOLDING CYCLE. The rubber compound or hot thermoplastic material is forced, by a screw or hydraulically operated ram, through gates and runners into the cavities of the mold. After cooling sufficiently (below 100°F), thermoplastic pieces are removed from the mold; vulcanized rubber articles are removed while hot. Molds may be either hot or cold during injection. Hot molds are lubricated with stearic-acid dust or a mild soap solution. Cold molds are lubricated with stearic acid. When the plastic compound incorporates a lubricant, the mold cavities do not have to be treated.

Injection molding of Geon plastics is as follows:

Ram pressures: 15,000 to 25,000 psi.

Plastic temperatures: 320 to 385°F.

Mold cavity temperature for best results: From 125 to 150°F.

Molding cycle: Determined by experiment. Somewhat longer time is allowed before removal of the parts after injection than for most other materials molded in this way. Cycle varies with hardness of compound.

Shrinkage of parts: Varies with total time cycle, temperature of plastic at injection, cross section of part, and size of gates.

Compression transfer molding resembles injection in that the blank is placed in an outer cavity and then forced by pressure through a channel into the mold cavity, which can be relatively cold. Heat required to make the charge flow is generated by pressure.

In molding thermoplastic materials, one of the greatest problems is to cool the product immediately after formation. When straight compression molding is used, the whole mold is cooled before removal of the parts, whereas rubber can be removed while still hot. A method that has been used with thermoplastics consists of heating blank pieces of compound to molding temperature, placing them in cold molds, and applying pressure. The parts cool quickly and can be removed virtually as soon as formed.

The Molded Product

The machine designer or other potential user of molded rubber parts can make things easier for the rubber molder and thereby lower costs of the parts by keeping his specifications in line with the limitations and characteristics of rubber compounds. Practically all new-product designs start out as rough ideas and rough drawings. The proper time to consider the size, shape, purpose, mounting, and other characteristics of any rubber parts involved is during these early stages of design. And the wise designer will consult experienced rubber technicians as soon as possible and seek their assistance in working out the final design of molded parts and the molds used for making them. All too often, rubber vibration-absorbing units, gaskets, grommets, and other parts are brought into the picture only after the rest of the machine has been designed and, perhaps, even after the dies for stamped metal parts have been made. Such a procedure invariably leads to trouble and increased costs.

Molded Rubber Compounds. Molded articles are made from crude and the various American rubbers. Lack of tack, which is characteristic of American-made rubbers, often makes it more difficult to do a molding job when using such compounds. However, rubber manufacturers have solved the major molding problems involving American-made rubbers, and are capable of producing excellent and wholly satisfactory molded articles from Neoprene, GR-S, Nitril, and other similar materials. Cost of articles molded from American rubber is generally greater than the

cost when crude-rubber compounds are used, but often better oil resistance and similar advantages make American rubbers preferable.

Because of the lack of tack exhibited by American-made rubber, molded articles in which two or more plies composed of it are joined have to be held together by crude-rubber cements placed between the plies before vulcanization. Tires are an example.

Physical Properties of Molding Compounds. The properties stated in Chap. 2 apply. The product designer should, when consulting a rubber manufacturer concerning a molded part, furnish complete information about the ways in which the part is to be mounted and used and the conditions of exposure to oil, light, weather, tension, compression, and other factors. Then the rubber manufacturer can make a better selection of the compound to be used for the part and often can do a better job of working out the shape and size.

Hardness: Usually the hardness range for soft rubber molded goods is

Crude rubber	15–90 durometer
American-made rubbers	30–90 durometer

Sometimes there is a question of whether a cushioning member should be made of a relatively soft or relatively hard vulcanized compound. Some factors involved in reaching a decision are given in the table.

Soft Compound	*Hard Compound*
Better cushioning	Inferior cushioning
Greater movement at given load	Lesser movement
Large volume desirable	Smaller volume can be used
Less load-carrying capacity	Better aging and chemical resistance

American-rubber molded parts exhibit better chemical properties and better resistance to aging, but they are inferior in some physical properties.

In many applications, the tensile strength of a molded piece is of no significance in judging service performance. Thus a motor mount subjected only to compression might have a tensile strength falling anywhere within a wide range and yet give maximum service.

Fastening. Improvements in methods of fastening rubber parts to metal and other materials have opened new design possibilities. The development of methods of vulcanizing rubber to metal with a bond greater than the strength of the rubber itself has eliminated, in many cases, the necessity for using mounting holes, bolts, metal flanges, and similar aids.

When mounting holes are necessary, they should not be placed too near edges or each other. The sketches show good and bad design.

Mounting bolts or screws sometimes can be made an integral part of the rubber piece by curing the rubber to the metal, as shown in Fig. 5*C*.

Rubber cushioning elements can be bonded, during molding, directly to metal mounting plates or other parts, eliminating the use of flanges, which were common before such bonding methods were perfected (see Fig. 5*D*).

Often a rubber molded part can be attached to a machine or similar product by molding a groove that permits the rubber to be snapped into

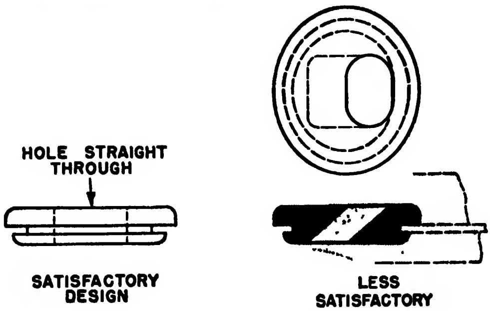


Fig. 8. Although rubber grommets are made in both the shapes shown, the one with the angular hole (*right*) is difficult to mold and remove from the cavity without splitting. Also, its mold is more costly to make and to maintain.

a hole or around a disklike member. A grommet for cushioning a hole edge is an example (see Fig. 8).

Flash Position. One important reason why a designer should talk things over with a rubber technician at an early stage in the development of a project is to determine how the molded part will be treated

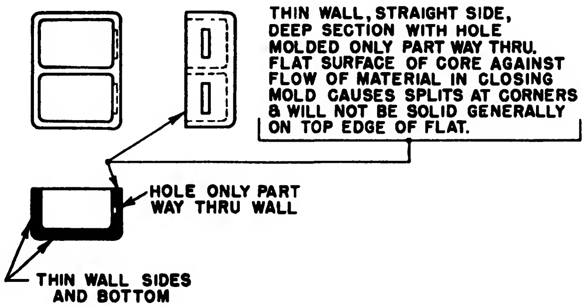


Fig. 9. A product of this shape may look simple, but it presents molding difficulties.

to remove the flash. The rind that is formed in compression molding is usually easy to remove simply by pulling it loose, but the thinner flash that connects rind and molded part is likely to present more difficult removal problems.

Trimming with dies, scissors, or a knife is easiest when the flash is located along an outside edge, as shown in Fig. 5*F*.

When the flash is positioned at a point along a flat or only slightly rounded surface between edges, it is more difficult to remove by cutting and has to be buffed, which is likely to alter the contour of the piece. A flash occurring in a concave surface is difficult or impossible to remove. Figure 5*G* shows an undesirable placement of flash.

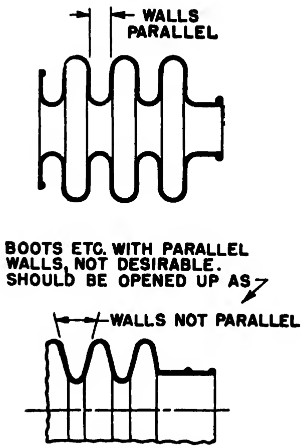


Fig. 10. A rubber boot such as those used on hydraulic-control equipment should not be designed with sides parallel as in the upper drawing, but should have more of a "sine wave" shape, as in the lower drawing.

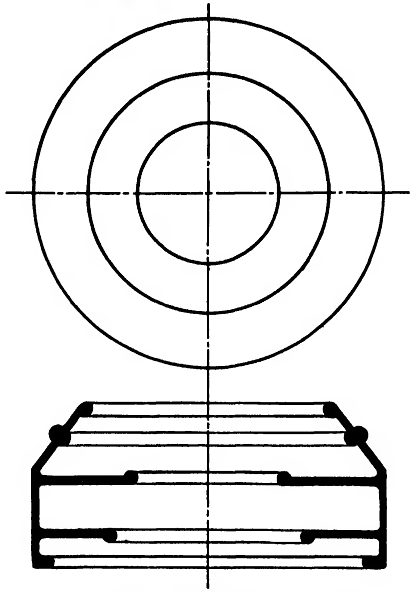


Fig. 11. This design for a molded part is not good because it involves a large object having thin walls and parallel surfaces at right angles to the walls. The mold, which would have to be of many parts, would be difficult to fill properly with rubber, and trouble would be encountered when attempting to strip the finished product from the mold.

When flash is removed by tumbling, the entire surface of the article may be roughened. This may not be objectionable, as in the making of rubber spring shackles. Tumbling also may alter dimensions considerably. Flash to be removed by tumbling should be located on an outer edge or surface. Relatively hard pieces are more quickly cleaned by tumbling than soft ones.

Flash positioning may seem to be a matter of mold design rather than product design. However, the two go hand in hand; and often if the shape of a molded piece is altered during the early stages of product designing, the way will be cleared for the mold designer to place the flash in the most economical position.

Edges. Whenever possible, extremely sharp edges and corners should not be specified in a molded rubber part. A radius, no matter how slight, is preferable. Sharp edges are likely to feather, and entrapped air may cause the edge to be jagged as a result of pitting. Figure 5*H* shows good and bad edge design.

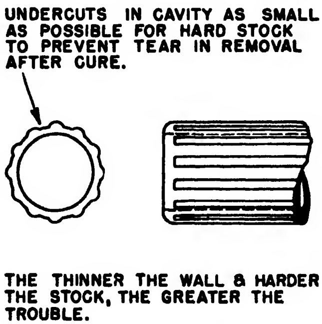


Fig. 12. Undercuts frequently cause trouble in molded-rubber-product manufacture and should be kept as small as possible, especially when a fairly hard compound is used.

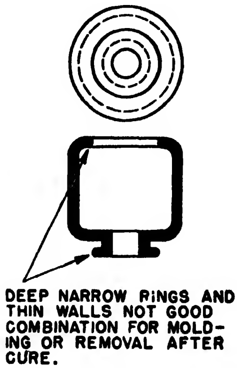


Fig. 13. An example of troublesome molded-product design.

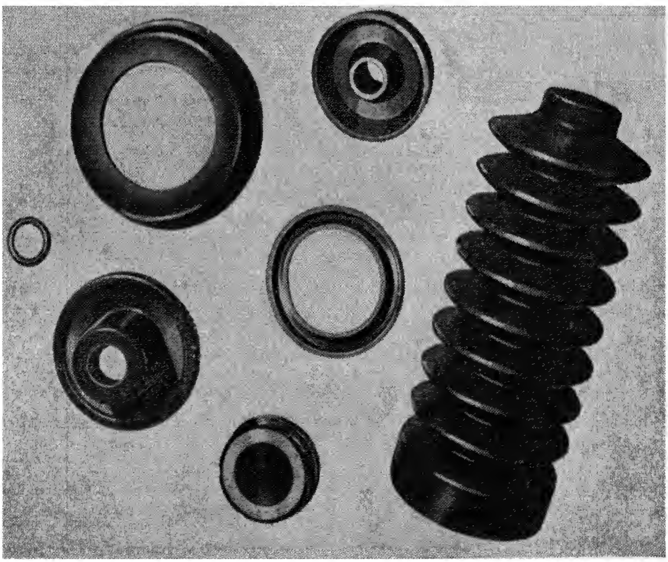


Fig. 14. These hydraulic packing items are typical molded-rubber products. The boot at right is shaped like the lower drawing in Fig. 10.

Shells, Bands, and Inserts. The outer surface of a metal insert such as a plain or threaded bushing should be roughened for maximum adhesion between it and the rubber. When such inserts are machined on a lathe, a coarse tool feed often will produce the desired surface roughness. When the end of an insert is flush with the surface of the rubber, it should be enlarged or flanged as much as possible to prevent the rubber from entering the cavity. Metal bands or shells should be roughened on their inside surfaces for maximum adhesion. When possible, the rubber should extend beyond and around one or both ends of the band for maximum shear resistance. In determining the diameter of a cylindrical shell, ring, or band, the expansion of the metal under the molding pressures to be used should be taken into consideration. That is, the metal piece should be made small enough so that when expanded, it will be the desired size and can be removed from the mold cavity. Figure 5*I* shows preferred insert and band forms and positions.

When the metal insert is to be held by buttons formed by passing of the compound through holes, it often is desirable to design the part and the mold so the compound can be forced through the holes from one surface. This is particularly true when American rubber is used. If two pieces of unvulcanized stock are placed in the mold, one on each side of the insert, the union between them, where the holes in the insert occur, may be imperfect. Figure 5*J* shows a typical "button" molding job.

Chapter 17

PACKING AND SHEET RUBBER

Rubber in sheet form and in combination with other materials such as cotton fabric, cork, or asbestos is used widely for making gaskets. Similar sheet material is made from plasticized polyvinyl chloride. Rubber manufacturers cut gaskets to required shapes and sizes, but much of the packing they make is sold in rolls to commercial gasket cutters. In general, "packing" is harder and less elastic than "sheet rubber."

While a great many varieties of sheet materials have been made, the following are typical:

NITRIL RUBBER. There is no swelling or deterioration in vegetable, animal, and mineral oils, fats, and greases. Heat resistance and oxygen resistance are better than for comparable crude rubber, and water absorption is less. Tensile strength is about 1,500 psi; elongation, 400 per cent. Hardness ranges from 65 to 75 durometer. The usual width is 36 inches, and standard thicknesses are 1/32, 1/16, 3/32, 1/8, 3/16, and 1/4 inch. Nitril rubber can be used with steam, air, hot and cold water.

NEOPRENE. There is slight swelling and no deterioration in oils and fats. Neoprene resists heat better than crude rubber and has less water absorption. Its tensile strength is about 2,300 psi; its elongation, 800 per cent; its hardness, 65 durometer. The dimensions are the same as Nitril. Neoprene is suitable for use with steam, air, hot and cold water.

RED SHEET RUBBER. This nonblooming sheet rubber packing is suitable for use with hot and cold water at pressures to 125 psi. Its standard width is 36 inches; standard thicknesses, 1/16, 3/32, and 1/8 inch.

DIAPHRAGM PACKING. This has one or more insertions of fabric. It is used for regulator diaphragms. Its width is about 45 inches; standard thicknesses, 1/16, 1/8, 3/16, and 1/4 inch.

CLOTH-INSERTED PACKING. This is made usually of black compound, with a cloth insertion for each 1/16 inch of thickness. Its width is about 37 inches; standard thicknesses, 1/16 and 1/8 inch.

COMPRESSED ASBESTOS PACKING. This is made of asbestos fibers with crude or American rubber as a binder. It is used for making gaskets

for service in oil refineries, power plants, manufacturing plants, refrigerators, airplane engines, etc. Numerous grades have been made, but the following cover most requirements:

1. Soft fiber sheet suitable for gaskets that must be soft and flexible and that will be used where service conditions are not severe.
2. All-purpose packing suitable for steam pressures to 350 psi with temperatures to 600°F.
3. Higher quality packing, for steam pressures to 400 psi and temperatures to 650°F.
4. Packing that is not affected by gasoline, oils, or refrigerants. Used at pressures to 700 psi and temperatures to 700°F.

Asbestos-packing sheet sizes range to 120 by 120 inches. The following are typical thicknesses and weights:

Thickness, in.	1/64	1/32	1/16	1/8
Weight, lb/yd²	1.3	2.6	5 2	10 1
Weight, lb/1,000 in²	1	2	4	7 8

KOROSEAL SHEET. This is not affected by strong corrosives and is not swelled by oils or other rubber solvents. It is virtually impermeable to gases and does not absorb moisture. Freedom from sulfur makes it usable with silver, brass, and other materials attacked by sulfur. Koroseal sheet exhibits other Koroseal properties as described in Chap. 23. It should not be used in contact with food products except when specifically compounded for such service. It softens above 150°F. Specific gravity of Koroseal sheet is 1.32. Its tensile strength is 2,200 to 2,700 psi; elongation, 250 to 300 per cent; hardness at 86°F, 75 to 84 durometer; thickness tolerance, ±0.005 inch; sheet width, 36 inches; thicknesses, 1/32, 1/16, 3/32, 1/8, 1/4 inch.

RUBBER SHEET. This is suitable for marine port and hatch gaskets and other types, bumpers, pads, and general-utility purposes. A typical medium soft grade has a hardness of 65 to 75 durometer, good aging properties, and good tensile strength.

TABLE 1. TYPICAL CHARACTERISTICS OF STOCK SIZES (40-IN. WIDTH)*

Thickness, In.	*Weight, Lb/Ft²*
1/16	0.44
3/32	0.65
1/8	0.86
3/16	1.30
1/4	1 73
5/16	2.16
3/8	2.59
1/2	3.46
5/8	4 32
3/4	5.18

* Special sizes are available on order.

CHUTE LINING. This is soft, elastic rubber for covering surfaces as protection against abrasion (see Armorite, page 333).

CUTTING GASKETS

Several methods of cutting gaskets and other articles from sheet rubber or rubber bonded sheet materials are in use. These include the following:

1. TEMPLATE AND HAND KNIFE. Used for large gaskets. Knife must be sharp. Water is generally used as a lubricant, and is applied to surface

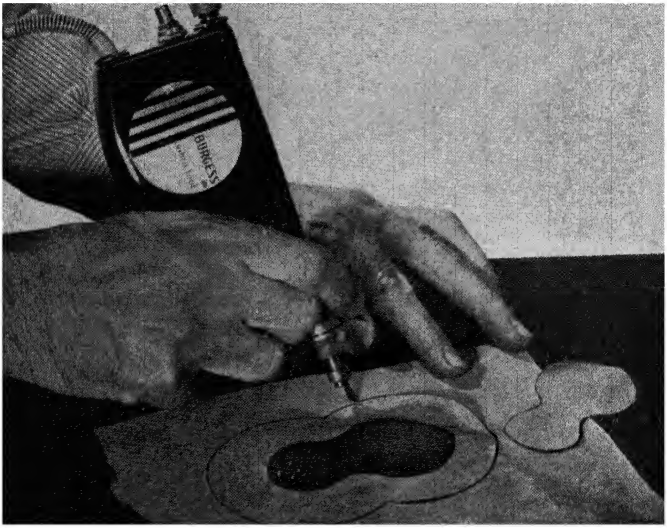


FIG. 1. Using a vibrating knife to cut dry 0.025-inch pure-gum sheet rubber. The blade, making 7,200 cuts per minute on 60-cycle current, may be guided by a ruler or metal template. This method produces a clean-cut edge without undue drag and without causing the rubber to wrinkle.

of sheet with a sponge or brush. Thin stock (to about 0.045 inch) is most difficult to cut because of its tendency to stretch and fold.

2. VIBRATING KNIFE. One of the vibrator devices such as the Burgess Vibro-Tool, which operates at 7,200 strokes per minute on 60-cycle current, can be used for rapid, clean cutting of thin gasket material. No wetting is required. The knife is sharpened like a skew chisel, the cutting edge making an angle of about 30 degrees with the back, and is usually held with its back approximately perpendicular to the surface. A metal ruler may be used as a guide for straight cuts, or a metal template for irregular cuts. The rubber should rest on a fairly rigid surface such as

semihard rubber, Masonite Presdwood, or some similar material that will not damage the blade.

3. Handle Dies. These are steel dies having sharp cutting edges. The stock is supported on a flat pad of fairly rigid rubber, wood, zinc, or similar material, and the die is placed on it and struck with a mallet. The blade edge may not make a straight cut but instead may produce an edge that is convex or concave.

4. Hollow Drill. This tool, operated by a drill press or hand brace, consists of a hollow tube with one end sharpened to a cutting edge, the bore curving sidewise to an opening in the tool some distance from the cutting end. The drill resembles a conventional leather punch. Water is used as a lubricant. This tool works well on stock $\frac{1}{4}$ inch or thicker. Maximum hole size that can be cut readily is about 1 inch.

5. Gasket Cutters. Various tools of this type are on the market and can be used on rubber packing that is thick enough to resist distortion while being cut. A typical gasket cutter consists of a cylindrical body equipped with a pilot rod or a twist drill acting as a pilot, an adjustable cross arm, and one or two cutter holders clamped to the arm. The cutters should be knife-shaped. The device can be operated by a drill press or a hand brace or drill. A hand-operated gasket cutter of another type consists of a steel-block head pivoted around a pin that is forced through the sheet material and engages a bushing in a wooden base. The cutting element is a blade resembling that used in a single-edged safety razor.

6. Steel-rule Dies. These can be made up in any shop. Such a die consists of a cutting rule, which is a steel strip sharpened along one edge, held in a wooden base. The contour it is desired to reproduce is marked on a piece of plywood (usually about $\frac{3}{8}$ inch thick) and is cut with a band saw or jig saw; the cut should be about the same width as the rule thickness. The rule is bent to the same contour, special bending machines being available for the purpose, and is forced into the saw cut until its back edge is flush with the back of the plywood. Sometimes the rule is notched at intervals along the back and staples driven astraddle it to hold the wood more securely. Such dies can be used in a clicking press, punch press, printing press, or any similar kind of machine. Rubber sheet or other material to be cut is backed with a suitable pad. Thin stock may have to be backed with paper or thin cardboard to produce a clean cut. Cutting rule is available in various degrees of hardness. The softer grades are used where bends must be made; the harder grades for straight cuts and those only slightly curved.

For mass-production cutting of gaskets and other products, welded or other "solid-type" clicking dies, and self-unloading machine dies which often are elaborate and costly, are used.

Chapter 18

RUBBER PRINTING MATERIALS

In the printing of designs, letters, and figures in one or more colors, rubber performs a number of important services better than other materials. For example, if you desire to print a trade-mark on some easily crushed material like corrugated cardboard, a rubber printing plate will be your best means. Often such a plate provides the only practical way of performing a tricky job in product decorating, lettering, or packaging.

Forms in which rubber printing materials are available include the following:

Unvulcanized stock for making molded printing plates and dies.

Unvulcanized gum for stamps, type, band daters, sign markers, and toy printing sets.

Engraving rubber (vulcanized) for making hand-cut printing plates and dies.

Offset blankets, printing-press rollers, sponge rubber for cushioning rubber stamps.

Cements for attaching plates and dies to wooden blocks, press rolls, sponge rubber, etc.

Adhesive fabrics for attaching plates and for backing plates to reduce shrinkage.

Applications

Rubber plates and dies may be used for printing the following:

Designs and lettering on cotton, paper, and burlap bags.

Glassine, cellulose film, and similar materials.

Corrugated signs, name plates, tags.

Large advertising displays.

Wallpaper.

Trade-marks and other matter directly on machine parts and other products.

Business forms, blanks of all sorts.

Multigraph work.

FIG. 1. Molded-rubber printing plates attached by means of adhesive fabric to press plate cylinder for printing wallpaper.

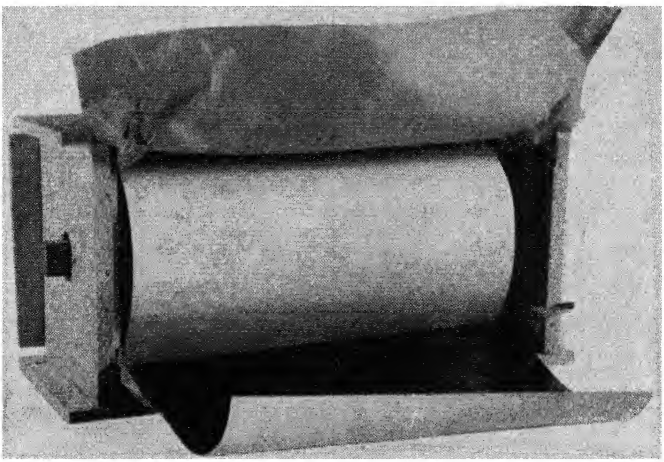


FIG. 2. A roll of unvulcanized printing rubber crated for shipping. It is suspended so no part can touch the box. Stamp gums, frictioned fabrics, and adhesive fabrics are packed in the same manner.

Halftone reproductions up to about 100 lines per inch.
Books (novels have been printed entirely from rubber plates).
Price cards, factory and store placards, posters.
Greeting cards and folders.
"Linoleum-block" designs. Rubber rivals linoleum for hand engraving.
Envelopes, letterheads, labels, and other letterpress work.
Hand-stamp work of all sorts.

Unvulcanized Printing Rubber

This compound, generally sold in sheet form backed by Holland cloth, may be of crude, GR-S, or Nitril rubber. Crude-rubber compounds, because they soften when first heated during vulcanization, require less vulcanizing pressure than American-made rubbers. They have good storage life. Crude rubber is softened by most oils and by gasoline, kerosene, and similar solvents used as type cleaners.

GR-S possesses about the same general properties as crude-rubber compounds but requires greater curing pressures. It is not resistant to ink oils and solvent cleaners.

Nitril rubber is superior to GR-S and crude rubbers in resistance to inks, cleaners, and wear. Its various characteristics when used for printing plates may be summarized as follows:

1. Is proof against cleaning fluids such as gasoline, kerosene, and carbon tetrachloride. Acetone should not be used to clean it.
2. Will not swell when used with oil and lithographic varnish-base inks, with acid aniline inks, or with manganese and cobalt driers.
3. Resists heat better than crude rubber.
4. Because of its stability, contributes to the maintaining of equalized printing pressure.
5. Has good abrasive resistance.
6. Exhibits uniformity in molding, has considerable latitude of vulcanizing time, and does not cause deposits on matrices.
7. In use, printing-plate pressure does not increase gradually as with crude rubber, because Nitril rubber is not swelled by oily inks.
8. Costs more than crude rubber, but this is offset partly by the fact that the specific gravity of the American-made rubber is less, so that each pound will provide greater printing-plate area than the same weight of equivalent crude-rubber compound, and partly by the fact that it has a longer service life (200 to 300 per cent).
9. American-rubber facing can be applied to a crude-rubber backing to give practically all American-rubber advantages and permit easier cementing to metal.

The technique of making printing plates is essentially the same for crude, GR-S, and Nitril rubbers, there being some variations in vulcanizing time and pressure. Vulcanizing presses developed for plate making have rugged platens that do not bow under pressure and that can be heated by steam, electricity, gas, or oil. Platen separation when the press is closed is held to very close limits by steel "bearers" or spacing strips. Thickness of a vulcanized plate can be held within 0.001 or 0.002 inch of gauge.

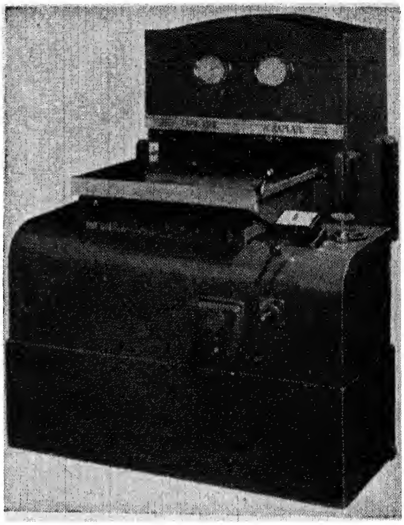


FIG. 3*a*. A typical vulcanizer for molded-rubber printing plates. Although the space between the press platens is not great, this type of vulcanizer can be used for manufacturing other rubber products.

MATRIX. Two types are in general use:

1. Resin-faced or resin-impregnated composition sheet. This is forced against the Aquadag-coated[1] metal type or engraving to be reproduced, at a temperature of about 307°F, which causes the resin to soften and flow into depressions. (Wood-mounted electros are not usually substantial enough to withstand the pressure required.) Continued heating under pressure hardens the resin. The matrix is stripped from the type while still warm. Bakelite is a commonly used matrix resin.

2. Clay matrix. Metal or wooden type is pressed into metal-backed prepared clay, which is then hardened by drying and used as a mold for the rubber.

MOLDING A CRUDE-RUBBER PRINTING PLATE. The making of a plate having a finished thickness of 0.110 inch is a typical example:

1. Floor thickness of matrix, measured from back to bottom of type impression, is 0.200 inch. Letter depth of matrix is no more than 0.045 inch. Bearers of the mat floor thickness (0.200 inch) are placed around the matrix on the lower vulcanizing press platen.

2. Holland cloth is stripped from a sheet of unvulcanized printing rubber 0.045 inch thick and 0.25 inch larger all around than the matrix. Sheet is dusted on stripped surface with corn starch to prevent sticking, and this surface is placed next to matrix.

3. Treated fabric or paper 0.010 inch thick and 0.5 inch larger all around than the rubber is placed on unvulcanized gum.

[1] Aquadag is a mold-release preparation.

4. Bearers are added to limit platen separation to over-all matrix thickness (average letter depth added to floor depth) plus 0.015 inch.

5. A strip of Holland cloth 3 inches larger all around than assembly is centered over rubber and fabric or paper.

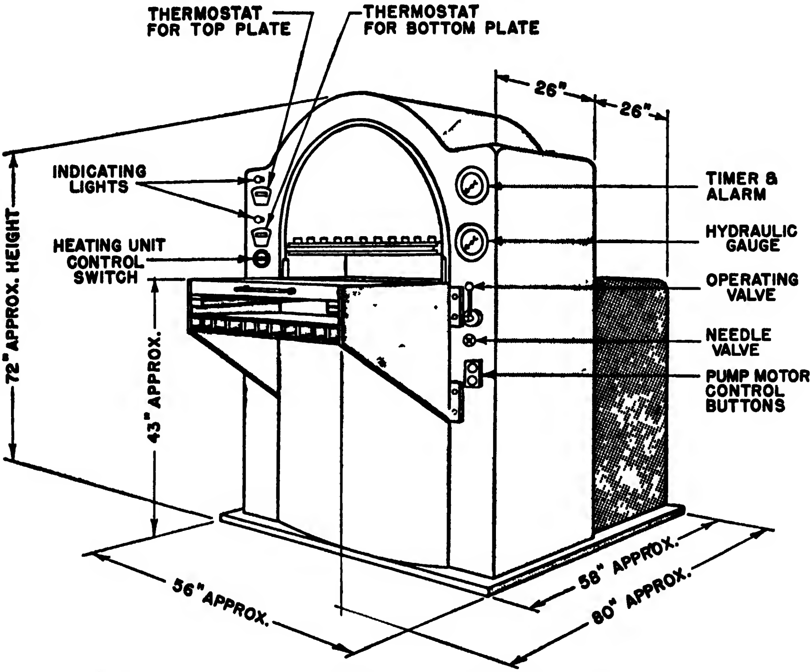


FIG. 3b. Parts and principal dimensions of a typical vulcanizer for curing rubber printing plates.

6. Rubber is vulcanized 7 minutes at 307°F (or under time and temperature conditions specified for the compound used). This produces the "preformed" plate.

7. Press is opened, Holland cloth stripped off, and over the vulcanized area a sheet of 0.045-inch unvulcanized gum the same size as first sheet is placed, stripped surface next to the back of preformed sheet. Calender grain of sheets must match to lessen shrinkage.

8. Bearer strips are added on each side of materials to make platen separation equal to matrix floor thickness of 0.200 inch, plus desired plate thickness of 0.110 inch, plus 0.005-inch allowance for the Holland cover, a total of 0.315 inch.

9. With Holland sheet over unvulcanized area but not bearers, and a piece of smooth sheet metal over the entire assembly, press is closed.

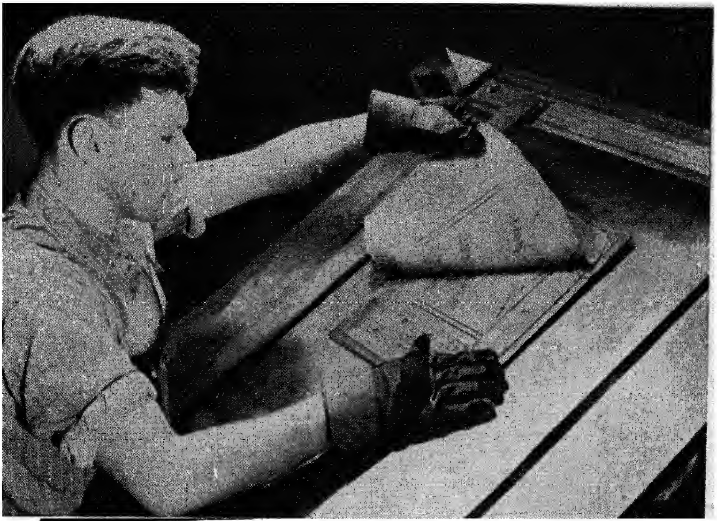


Fig. 4. Removing a molded-rubber printing plate from the resin matrix against which it was vulcanized.

Fig. 5. Checking the gauge of a rubber printing plate before installing it on a press.

Rubber is vulcanized 5 minutes at 307°F (or as otherwise required for the compound used).

The foregoing is a typical procedure for making a crude-rubber plate. When Nitril rubber is used, the procedure is approximately the same,

TABLE 1. SOME CHARACTERISTICS OF TYPICAL UNVULCANIZED RUBBER PRINTING-PLATE MATERIALS

Arbitrary grade designation	*Durometer hardness*	*Applications and remarks*
1	30	Corrugated-container printing. Excellent for solids on boxboard
2	45	
3	55	Excellent all-purpose rubber, suitable for hand stamps, bag and corrugated-container dies, multigraph plates
4	65	Container printing, general printing, aniline ink printing
5	75	Bag printing, corrugated-box certificate dies, fine lines, and fine-type reproduction
6	70	Special compound for use with acids, as in aniline ink work and acid etching of steel (strong nitric acid and silver nitrate solution being one form of steel etching "ink")
7-GR-S	30–80	Similar to crude-rubber applications. Vulcanizes in 12 to 15 min at 307°F. Specific gravity from 1.15 to 1.31
8-Nitril (Ameripol D)	30–75	Unaffected by oils, gasoline, kerosene, carbon tetrachloride, but may be harmed by acetone. Vulcanizes in 12 min at 307°F. Specific gravity 1.15 to 1.38
9	55	Medium hard rubber vulcanizing in 8 to 10 min at 307°F
10	65	Slightly harder than 9. Same vulcanizing time
11	50	Low specific gravity stock. Vulcanizes in 6 to 8 min at 307°F
12	60	Suitable for making numerous cures in same mold. Vulcanizes in 10 min at 307°F
13-GR-S	55	Synthetic gum with specific gravity of 1.38. Vulcanizes in 15 min at 307°F

TABLE 2. TYPICAL DIMENSIONS

Material	*Thickness range, in.*	*Width range, in.*
Printing-plate material	0.060– 3/16	18 to 36
Rubber-stamp gum	0.060–11/32	18, normally

with the following exceptions: Treated paper is used instead of fabric to resist shrinkage. Curing time for the first or preformed plate is 4 minutes at 307°; final curing time is 12 minutes at 307° (or whatever other time and temperature are specified for the compound being used).

Controlling Shrinkage. The final rubber printing plate must be a faithful reproduction of the original type or engraving. This means that shrinkage must be reduced to a minimum in both the matrix and the plate. Ways in which this is done include

1. The matrix stock is designed to minimize shrinkage, and metal or other reinforcements are used. Thus, a perforated metal sheet may be sandwiched between two pieces of matrix stock. During heating under pressure, matrix material and metal merge into a unit.
2. Plate shrinkage and curl are reduced by always placing grain of unvulcanized rubber in one direction in the mold. The grain runs lengthwise of the rolled strip.
3. Plate shrinkage is reduced by embedding a layer of metal or other material in the rubber or using it as a backing. Such reinforcing materials include sheet brass or aluminum, fine wire screen, friction fabric, or resinous paper or cloth.

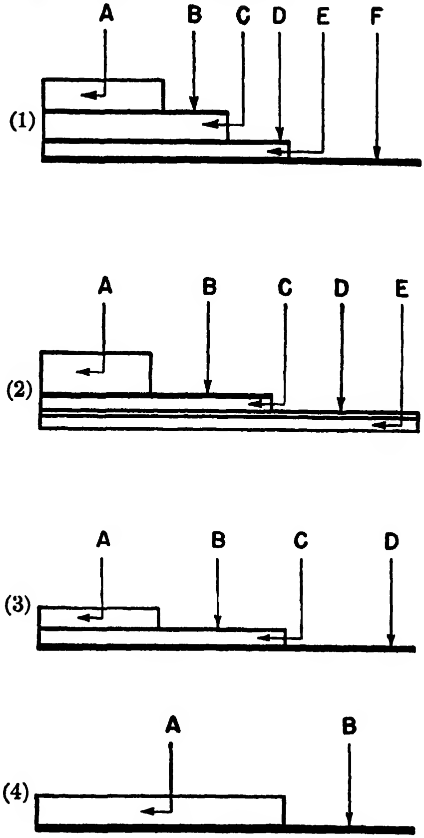


Fig. 6. Typical constructions of vulcanized engraving rubber:

(1) Heavy-gauge engraving rubber 1/4 or 5/16 inch thick. The various parts are *A*, face stock; *B*, cloth insertion; *C*, filler; *D*, cloth insertion; *E*, filler; *F*, heavy duck backing.

(2) Buffed engraving rubber 1/4 inch thick. *A*, face stock; *B*, cloth insertion; *C*, filler; *D*, two cloth insertions, *E*, buffed rubber back.

(3) Light-gauge engraving rubber 3/32 or 1/8 inch thick. *A*, face stock; *B*, cloth insertion; *C*, filler; *D*, bare duck backing.

(4) Gouge engraving rubber 3/32 or 1/8 inch thick. *A*, face stock; *B*, bare duck backing.

Engraving Rubbers

Vulcanized rubber in sheet form is used widely for making hand-cut printing plates. The design is cut with a knife or engraved with a gouge to form a plate that is used like any other type or a linoleum block for printing. The sheet can be used for making special hand stamps for marking products or containers.

Large sheets of engraving rubber are made with thickness held throughout to +0.000 and −0.005 inch. Engraving rubber for use on rotary presses is made with a backing that causes the sheet to curve so it matches the contour of the press plate cylinder. This makes cementing more secure, thus permitting high press speeds, and it lessens plate distortion.

Two widely used types of engraving gum are (1) a layer of face stock having a bare duck backing and used for gouge-type engraving and

TABLE 3. SOME CHARACTERISTICS OF TYPICAL VULCANIZED ENGRAVING RUBBERS

Arbitrary grade designation	*Durometer hardness*	*Application and remarks*
1	75	5/16 in. thick, two layers of cloth insert. Cloth and paper bag printing
2	75	5/16 in. thick, 3/16-in. face stock, one cloth insert. Replaces No. 1 where shorter runs are required
3	75	Similar to No. 1, but is 1/4 in. thick
4	65	Similar to No. 3, but with softer face. Used also for metal printing
5	35–45	Extra soft, for printing corrugated cardboard
6	90	Gouge-type rubber 3/32 or 1/8 in. thick, for printing on metal
7	90	One cloth insert. Designed for medium-service letterpress work
8	75	One cloth insert. Designed for letterpress work
9. Zinc back-1	. . . .	Single cloth insertion with zinc backing. 1/4- to 3/8-in. gauges with 1/8- or 3/16-in. face. Zinc 1/16 or 9/10 in. thick
10. Zinc back-2		Tint block and general letterpress service. Gauge, 0.148 in.
11. Zinc back GR-S	75	Thickness 1/4 to 3/8 in. face, 1/8 in. Metal sheet 1/16 by 36 by 72 in.
12. GR-S	40–85	Available in thicknesses of 3/32 to 5/16-in.; face thicknesses 1/16 to 5/32 in.; normal width 40 in.
13. Nitril (Ameripol D)	35–75	Oil and wash resistant. Over-all thickness, 3/16 and 1/4 in.; face thickness, 1/8 and 5/32 in.; normal width 40 in.

(2) laminated sheet consisting of one or two layers of cloth between face and filler stock. Cloth acts as an easily felt "stop" for the engraver's knife. Different types of engraving rubbers are shown.

MAKING AN ENGRAVED PLATE (cloth insert stock). With a sharp knife, the engraver cuts vertically or at a steep angle through the face stock, until feel tells him that the knife point touches a cloth layer. He peels unwanted, nonprinting areas from the cloth layer, leaving the design in clear-cut relief. For letterpress printing, rubber having a single cloth insert is adequate. For heavier carton and bag printing, rubber

having two cloth layers is preferable. When deep depressions are needed to prevent smudging between widely spaced printing areas, the cut is made to the second cloth layer.

Gouge Engraving Rubber. This is used mainly for making metal-sign printing plates and for supplanting linoleum blocks. Design is formed with an engraving gouge, as in linoleum carving.

Engraving gum is made of crude, GR-S, and Nitril rubber. Typical face stock thickness range is from 1/8 inch upward.

Some Aspects of Printing with Rubber

The importance of rubber-plate printing is indicated by the fact that presses are being manufactured specially for this type of work. Some advantages claimed for rubber plates include

Presses can be run faster.

Presses are subjected to less wear and tear because of rubber's superior cushioning properties.

Use of rubber printing plates requires less press down time than when the plates are metal. This is because rubber is easier to attach to the press cylinders (with cement). Use of rubber plates in conjunction with removable rotary press cylinders further speeds the process of changing plates and getting the press into operation.

Ink consumption is about 25 per cent less with rubber than with metal.

Rubber plates, using aniline inks, not uncommonly make runs or more than a million impressions. With oil inks, the figure may approach half a million.

Press pressure must be reduced to a minimum so the plates make a "kiss" impression. When crude rubber is used, slight swelling after contact with oily ink necessitates a readjustment of pressure.

Printing Rollers. Rollers for printing presses are made of crude rubber, Nitril rubber, and Neoprene compounds. They are used in newspaper and rotogravure printing and for a wide variety of other applications where formerly only glue-composition rollers were employed.

Crude-rubber rollers are swelled by oils used in printing inks. This swelling, however, creates a surface that is highly efficient for spreading ink. The rate of swelling is frequently sufficient to offset all loss from regrinding the roller. Thus a roller on a newspaper press may swell enough to permit grinding off an inch a year; yet at the end of several years it will still have its original diameter! Oil-resisting American-rubber rollers do not swell in the presence of inks and are not affected by cleaners such as kerosene and gasoline.

Roller durometer hardness ranges from 10 to 95.

SPONGE RUBBER. Sponge stock is used as an insert between the type and handle of rubber stamps to provide cushioning and to facilitate printing on irregular surfaces. Sponge stock for such service is held within ±0.010 inch of a given gauge, with no variation of more than 0.005 inch in any one sheet.

FIG. 7. Rolling a vulcanized rubber printing plate into contact with a base fabric preparatory to placing the plate on a printing press.

ADHESIVES FOR PRINTING MATERIALS. Adhesives used in attaching rubber printing plates and dies may be classified as follows:

Adhesive Fabric. This fabric has both surfaces coated with tacky rubber compound. It is used to attach molded rubber printing plates to printing-press cylinders or cylinder saddles.

Friction Fabric. This is used to reinforce rubber die or plate and reduce shrinkage, to improve bond between rubber and cement, as a bond-

ing agent between rubber and spring brass in multigraph plates, and as a backing for the rubber in hand dating stamps.

Backing Material. This is one- and two-ply fabric reinforcement for rubber printing plates to reduce shrinkage of plate. Paper reinforcement is also used.

Cements. Various rubber cements are used to improve adhesion of friction or adhesive fabric, to attach rubber plates to wooden blocks to make them type-high, and to fasten rubber stamps to handles. B. F. Goodrich Vulcalock cement is one of the strongest adhesives for attaching rubber plates or dies to metal.

OFFSET BLANKETS. Rubber blankets are used widely in offset printing. Their durometer hardness is around 70. Blankets are made of crude, GR-S, and Nitril rubber.

STORING PRINTING RUBBER MATERIALS. Unvulcanized and vulcanized materials should be stored in a cool, dry, and dark place. To assure adequate freshness, many plants purchase only enough unvulcanized stock to meet 60 to 90 days' requirements. American-made rubber compounds, either cured or uncured, remain stable in storage.

Reminder: When printing with rubber, use as light press pressure as possible.

Chapter 19

RUBBER-COVERED ROLLS

The superiority of crude- and American-rubber compounds as coverings for rolls, rollers, and pulleys has been demonstrated over a period of many years.

The papermaking industry is the largest user of rubber-covered rolls, with the steel, textile, and tanning industries ranking next in order.

Core Material

Cast iron and steel are commonly used for the cores of rubber-covered rolls, although aluminum and other metals have been employed. For many years, practically all roll cores were made of cast iron. This is still the standard core material for paper-mill press rolls, largely because of its weight and resistance to deflection.

Hard Rubber in Covering

Soft rubber cannot be vulcanized satisfactorily to a cast-iron core. During vulcanization, heat drives gases out of the porous iron, causing blisters in the covering and resulting in early service failure. To reduce this trouble, a hard-rubber base is interposed between the core and the soft-rubber cover. First the iron cylinder is threaded on a lathe to increase roughness and area. During vulcanization, the hard rubber shrinks into the threads, forming a purely mechanical bond. Gas bubbles form in hard rubber less readily than in soft. To permit the escape of any gas that may be imprisoned between base and core, cotton strings are laid lengthwise over the core surface. These act as gas ducts. However, a sudden liberation of gas may blister the hard rubber. The soft-rubber covering and hard-rubber base are vulcanized simultaneously.

Friction is the only force that holds the hard rubber on the iron core. During vulcanization, the hard rubber may flow and become distorted, and the resulting distortions may cause the soft outer covering to develop corrugations in service. Or the presence of gas-conducting strings may

result in similar surface irregularities. The hard rubber contributes nothing to the cushioning effect of the roll covering. Roll cores are re-covered when the soft rubber becomes unserviceable. When hard rubber is used, the core has to be rethreaded—reducing its diameter ⅛ to ¼ inch. Often the rubber cover has to be increased in thickness to compensate for this reduction, with consequent increase in re-covering cost.

Vulcalock Covering

In the Vulcalock roll, hard-rubber troubles are eliminated. Although it is difficult to vulcanize soft rubber to cast iron, it can be vulcanized

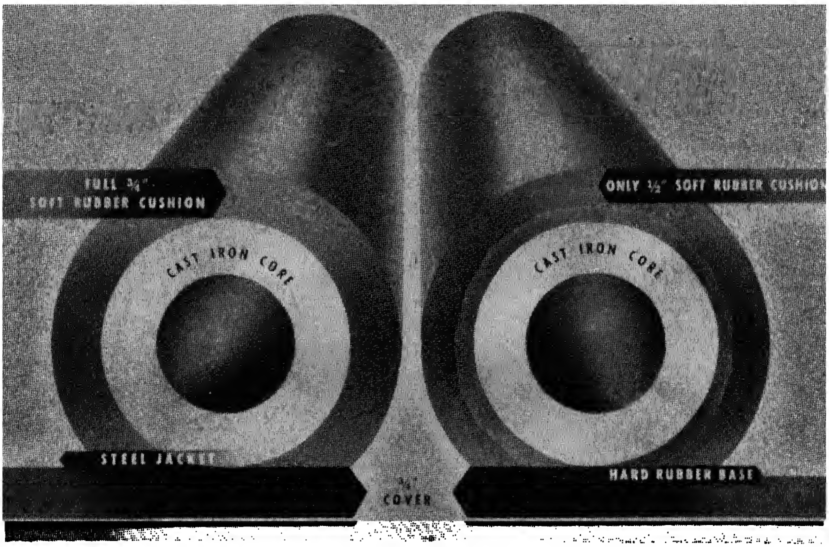


Fig. 1. (*Left*) A steel-jacketed Vulcalock press roll whose rubber cover is bonded to the steel. (*Right*) A similar roll of conventional construction in which a hard-rubber base is used to bond the soft covering to the cast-iron core.

to steel, aluminum, and other nonporous metals. When a Vulcalock roll has a cast-iron core, the iron is sheathed in a welded steel jacket usually ¼ inch thick, and it occupies space provided by machining down the iron core, so the soft rubber covering is not robbed of any thickness. By vulcanizing a special rubber having low affinity for water to seamless steel tubing, lightweight, low-inertia paper-machine table rolls are made.

Some features of Vulcalock roll covering follow:

The rubber is bonded directly to the core with an adhesion of more than 500 psi.

Soft rubber of uniform density extends all the way to the core. A

Vulcalock roll may have 50 per cent more rubber cushion and give 100 per cent more service than one having a hard-rubber intermediate shell, diameters being equal.

The increased cushion prolongs felt life in papermaking machines.

Elimination of core threading, strings, and hard-rubber base tends to prevent corrugations or other marks that sometimes appear on soft- and medium-density rolls operated under heavy pressure. Longer service between grindings to true the rubber surface is generally the rule because of increased rubber toughness resulting from high vulcanizing pressure.

To prepare a Vulcalock roll for re-covering, the core is merely sandblasted after removal of the old rubber.

An old cast-iron core can be restored to its original diameter by installing a steel jacket, thus permitting normal rubber thickness.

Vulcalock press rolls are vulcanized hydrostatically at a pressure of 225 psi.

Compound Characteristics

Hardness and other characteristics of roll covering compounds are determined by

1. Roll loading
2. Roll speed
3. Chemical resistance required
4. Cutting or abrasive properties of product handled
5. Degree of moisture elimination required (as in paper-mill rolls)
6. Resistance of product to staining.

Plastometer Testing

The Pusey & Jones Plastometer, used almost universally for measuring hardness of rubber roll coverings, has an indentor tipped normally with a ⅛-inch steel ball and loaded with a 1-kilogram weight. Depression of the rubber by the ball, measured in hundredths of a millimeter, indicates the hardness of the compound. Sometimes, for very soft stocks, a ¼-inch ball is used.

The method of making a Plastometer test may be summarized:

1. Lower indentor and gauge until the ball touches the rubber.
2. Continue lowering indentor until gauge pointer makes three revolutions.
3. Set pointer at zero.
4. Lower the kilogram weight gently until it rests fully on indentor, as indicated by a space of about $\frac{3}{16}$ inch between the supporting plate and shoulder of the weight.
5. Allow the Plastometer to remain in this position for exactly 1 minute after application of the load.
6. Note the dial reading.
7. Take three readings, each at a different point, to provide an average.
8. Note temperature of room and therefore of the rubber compound. Comparative tests should be at the same temperature.

On the Plastometer scale, a zero penetration indicates maximum hardness of the compound, while penetrations of successively greater depth indicate increasing softness. Most roll coverings fall within the hardness range of 0 to 250, although some very soft rolls having a hardness in excess of 350 have been made.

Color of Rolls. In the textile industry, dark-colored coverings might stain the products handled. Textile roll-covering stocks are usually light buff, light yellow, or white. Rolls used for handling stainless steel must be nonstaining. Traces of a dark-colored rubber compound, transferred to the stainless alloy, might cause permanent discoloration during subsequent heat-treatment.

Protection against Chemicals. The rubber covering offers an effective way of protecting a metal roll from chemicals or rusting. The rubber can be extended over the ends, hubs or shoulders, and flanges to form a perfect seal against fluids, vapors, and gases. Bearing surfaces are not covered. The B. F. Goodrich internal-bearing couch roll used on cylinder-type papermaking machines rotates on roller bearings sealed to keep lubricant in and water out.

Paper-mill Rolls

The chief function of paper-mill rolls is to remove water from the sheet of pulp that is being converted into paper. To permit great pressures, paper-mill press rolls have cast-iron cores. The steel jacket in Vulcalock rolls does not change the total core weight appreciably, although it does add some stiffness. As a result of bearing loading with counterweights, the roll is bent slightly, its center arching upward. To maintain uniform contact across the sheet of paper, the surface of the roll has to be ground to a crown.

Selecting Roll Covering. Often, by selecting proper roll hardness, a paper-mill operator can offset waste elsewhere. If the cost of steam is abnormally high, the press rolls probably are not doing their jobs satisfactorily. If the steam cost is high but the felts wear longer than would normally be expected, the press rolls are probably too soft.

Where fuel costs are high, press rolls should remove as much water from the paper as possible before steam is applied for drying. Where fuel cost is not an important factor, it sometimes is an advantage to use softer rolls, regrind them frequently, and depend upon steam to remove a considerable percentage of the water.

Cost of removing a pound of water from paper with steam is about 25 times as great as with rubber-covered rolls. Sometimes the total drying cost can be varied 40 per cent or so simply by varying the hardness of drying rolls.

TABLE 1. RECOMMENDATION CHART, PAPER-MILL ROLLS

The numbers indicate Pusey & Jones Plastometer measurements of roll-covering density.

Fourdrinier machines

News	3 press	Suction couch, Suction first press	Top roll, Suction press, No offset	Second press	50
News	3 press	Suction couch, Suction first press	Top roll, Suction press, No offset	Third press	45
News	3 press	Suction couch, Suction first press	Top roll, Suction press, Offset	Second press	45
News	3 press	Suction couch, Suction first press	Top roll, Suction press, Offset	Third press	30
News	3 press	No suct. couch or first press, Speed 800–1,000 fpm		First press	70
News	3 press	No suct. couch or first press, Speed 800–1,000 fpm		Second press	50
News	3 press	No suct. couch or first press, Speed 800–1,000 fpm		Third press	30
News	3 press	No suct. couch or first press, Speed 600–750 fpm		First press	65
News	3 press	No suct. couch or first press, Speed 600–750 fpm		Second press	60
News	3 press	No suct. couch or first press, Speed 600–750 fpm		Third press	50
News	3 press	2 Suction presses		First pr. suction	
News	3 press	2 Suction presses		Second pr. suction	
News	3 press	2 Suction presses		Third pr.	30
News	2 Press, No suct. rolls			First press	60
News	2 Press, No suct. rolls			Second press	50
Book, Bond-Magazine	3 Press, Normal drying capacity		Top roll	First-second press	40
Book, Bond-Magazine	3 Press, Normal drying capacity		Bottom roll	First press	70
Book, Bond-Magazine	3 Press, Normal drying capacity		Bottom roll	Second press	65
Book, Bond-Magazine	3 Press, Normal drying capacity		Bottom roll	Third press	65
Book, Bond-Magazine	3 Press, Normal drying capacity			Smoothing press	80
Book, Bond-Magazine	2 press, Drying capacity taxed		Top roll	First press	10
Book, Bond-Magazine	2 press, Drying capacity taxed		Bottom roll	First press	50
Book, Bond-Magazine	2 press, Drying capacity taxed		Bottom roll	Second press	50
Book, Bond-Magazine	2 press, Drying capacity taxed			Smoothing press	80
Kraft	3 press	Suct. couch, Suct. first press	Top roll	First-second press	40
Kraft	3 press	Suct. couch, Suct. first press	Bottom roll	Second press	60
Kraft	3 press	Suct. couch, Suct. first press	Bottom roll	Third press	50
Kraft	3 press	No suction press	Top roll	First-second press	40
Kraft	3 press	No suction press	Bottom roll	First press	65
Kraft	3 press	No suction press	Bottom roll	Second press	65
Kraft	3 press	No suction press	Bottom roll	Third press	60
Kraft	2 press		Top roll		40
Kraft	2 press		Bottom roll	First press	60
Kraft	2 press		Bottom roll	Second press	50

TABLE 1. RECOMMENDATION CHART, PAPER-MILL ROLLS.—(*Continued*)

Cylinder machines

Chip-News Container etc.	Wringer rolls Top-bottom			70
	Primary presses	Normal service	Top	45
			Bottom	30
		Severe duty	Top	30
			Bottom	20
	Main presses	Normal service	First	20
			Second	20
			Third	30
		Severe duty	First	0–6
			Second	20
			Third	20
Straw	Top roll Suction press*			60
	Top roll First press*	Sheet ex. dry Speed under 200 fpm		40
		Normal operation		45
		Low vacuum Sheet wet		50
		Sheet ex. wet		60
	Bottom rolls Main presses	Normal service		20
		Severe duty		0–6
Tissue Toilet	Couch roll			250
	Bottom rolls Main presses	Normal service		45
		Severe duty		30

Yankee Fourdriniers

Top couch*			90
Top roll Suction pr.*			50
Main press	Normal service	Top roll	45
		Bottom roll	30
	Severe service	Top roll	30
		Bottom roll	20
Wringer rolls			140
Pressure roll	Normal service		30
	Severe service		20

* Recommend soft rubber doctor.

Extracting a pound of water with steam involves the following figures:

About 1.28 pounds of steam are required.

When the paper enters the driers at 60°F, 1143.8 Btu are required to heat and evaporate the pound of water.

1.28 pounds of steam liberate 1218.5 Btu at 10 pounds pressure.

The difference of 74.7 Btu, or a little over 6 per cent, is lost by radiation.

Table 1 shows the Pusey & Jones Plastometer hardness for paper-machine rolls.

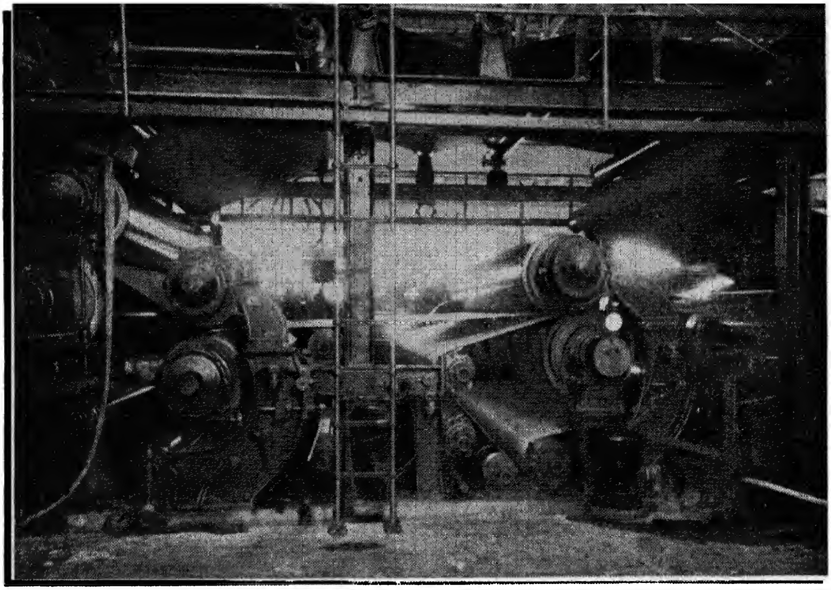


FIG. 2. Numerous rubber-covered rolls are used on a papermaking machine of this type.

TABLE ROLLS

It is desirable to have table rolls as light as feasible to decrease their inertia. Brass rolls and aluminum rolls covered with Micarta or with rubber attached by the Vulcalock process have been used widely. An improved type of table roll is made of thin-walled, lightweight seamless steel tubing covered with rubber. It is balanced dynamically at the service speed, and the rubber is ground and polished to make it touch the wire evenly. The rubber compound used on such table rolls is less easily wet by water than other kinds of roll surface. At high roll speeds, this lower affinity causes water to be thrown off the rubber at a lower tangent. Consequently, less water is carried back up to the wire, and water removal from the sheet is more rapid and thorough.

Press Roll Crowning and Grinding

Rubber-covered rolls are ground to finished size, shape, and smoothness. Paper-machine rolls under heavy loading require crowning to produce uniform contact. The amount of crown is usually determined approximately from a table. Such a table cannot be used as more than a general guide in determining the crown for a specific roll.

Table 2. Crowning of Rubber Press Rolls*
In thousandths of inch (diametrical measurement).

Diam., in.	*Face of roll, in.*																							
	20	*30*	*40*	*50*	*60*	*70*	*80*	*90*	*100*	*110*	*120*	*130*	*140*	*150*	*160*	*170*	*180*	*190*	*200*	*210*	*220*	*230*	*240*	*250*
6	6	19	43	78	132	210																		
8	3	8	18	33	55	90	140	200																
10	1	4	9	17	30	47	72	102	140	180	236													
12	1	2	5	10	17	27	42	59	81	105	137	175	215											
14		1	4	7	11	17	26	37	51	66	86	110	137	168	206									
16		1	3	5	8	12	18	26	36	46	60	77	96	118	144	172	202							
18		1	2	4	6	9	13	18	25	34	43	54	67	83	101	121	143	169	197	228				
20	.	.	1	3	4	6	9	13	18	24	31	39	49	60	73	87	104	122	142	165	189	217		
22			1	2	3	5	7	10	14	19	24	30	37	46	56	67	79	94	110	127	145	166	190	215
24				1	3	4	6	8	11	15	19	24	30	37	45	54	64	75	87	100	114	128	146	165
26				1	2	3	4	6	9	12	15	19	25	31	37	44	51	60	70	81	93	107	122	138
28				1	2	2	3	5	7	9	12	15	19	23	28	33	40	47	55	64	73	83	96	108
30	.				1	2	3	4	6	7	10	12	15	19	23	27	32	38	44	51	59	68	77	87
32	.				1	1	2	3	5	6	8	10	12	16	19	22	26	31	36	42	48	55	68	77
34						1	2	3	4	5	6	8	10	13	16	18	22	26	30	35	40	46	52	59
36							1	2	3	4	5	7	8	11	14	16	19	22	25	29	33	38	42	49

* This table, devised by the Pusey & Jones Co., is not intended to give the exact crown to be used for any particular roll but is to serve only as a guide to the relative amount of crown for various diameters and lengths.

Determining proper crown for a bottom press roll is usually a "custom tailoring" matter involving such variables as the following:

Core Construction. Differences in wall thickness, methods of applying journals, etc., influence the amount a roll springs. Increased springing requires greater crown. Cores rethreaded repeatedly for hard rubber gradually become thinner walled, thus requiring increased cover crown.

Rubber Density and Uniformity. For a given lever weight, a soft roll cover requires a slightly greater crown than a harder cover. If rubber density from end to end varies by no more than three or four points, the roll will hold its crown with satisfactory uniformity. When density varies by five or more points, a different crown is required. The softer areas will cause damp streaks, while the harder spots will take the pressure of the top roll.

Type of Top Roll. High top roll deflection requires high crown on the bottom roll. If the top roll is stone, having practically no deflection, the bottom roll requires a minimum crown.

Grade of Paper or Board. Paper made from a free stock drains faster under pressure than that made from a slow stock and requires less press roll crown.

Machine Whims. On older paper machines, when the paper dries too fast or too slowly at center and edges, adjusting the driers or other parts may not suffice; so the press roll crown is altered to provide proper control.

Machine Speed and Drying Capacity. Older machines often are speeded beyond their rated capacity without increasing drier capacity. So more water must be removed at the wet end by adding more weight to the press levers. This causes greater roll deflection, necessitating an increase in crown.

Checking Roll Crown. After a press roll has been ground to a crown thought to be correct, it usually is put on the machine and operated. Damp streaks in the paper indicate that the roll is not making uniform contact. So the rubber is sandpapered opposite the drier areas in order to reduce roll pressure there and permit better contact where the damp spots had been appearing.

When a new replacement roll is ordered or an old one sent to a manufacturer for re-covering, accurate information concerning the hardness and crown of rolls that have been giving satisfactory performance on the machine will reduce trial-and-error work.

Grinding Rubber-covered Rolls

The following recommendations for grinding rubber-covered rolls are based on experience of The B. F. Goodrich Company and on data obtained from equipment manufacturers, including the Farrell-Birmingham Company.

Sometimes it is desirable to use the same grinding wheel for refinishing both metal and rubber-surfaced rolls, although separate wheels are better. A fine-grit wheel that produces a good finish on an iron roll will load up quickly on rubber. When the wheel must serve for both iron and rubber, the coarsest wheel that will give a satisfactory iron surface should be used. A wheel of 40 grit, 4 grade has been found suitable for such dual service.

The best arrangement for refinishing rubber-covered rolls is to use two wheels.

For hard- and medium-density rolls (Pusey & Jones density 0 to 128) and soft density (over 125):

Roughing cut: 16 grit, 14 grade, bond C-14-R wheel.

Finishing cut: 24 grit, 14 grade, bond C-14-R.

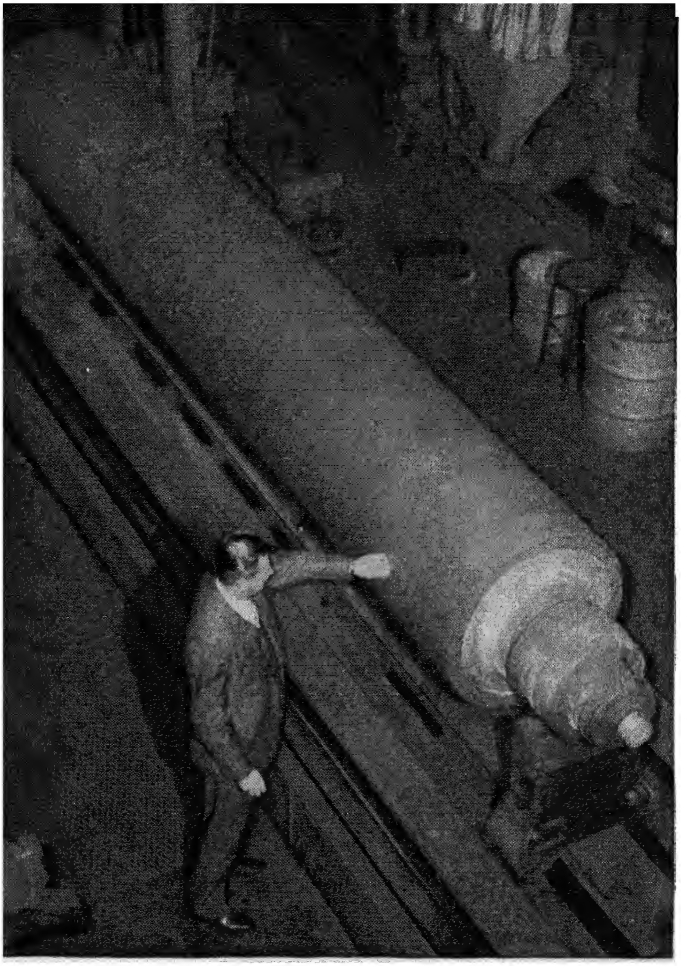


FIG. 3. A large paper-mill roll mounted in the factory for grinding to produce a finished surface.

For grinding table rolls, using single wheel:

Wheel 10 inches in diameter, 24 grit, 14 grade, bond C-14-R, speed 3,700 rpm.

For grinding large rolls, using single wheel: A Carborundum Redmanol wheel 18 inches in diameter, 2 inches wide, is recommended. Grinding-

wheel speed, 1,200 rpm. Roll speed in same direction as wheel, 20 rpm. Carriage feed, 8 to 10 inches per minute.

Depth of roughing cut:

Hard rolls (0 to 25 density, using ⅛-inch ball): 0.015 to 0.020 inch.

Medium rolls (25 to 125 density): 0.030 to 0.040 inch.

Soft rolls (126 density and softer): 0.030 inch or less.

Depth of finishing cut: In all finish grinding, the wheel is not fed into the work but is locked at a position where it just makes contact with all

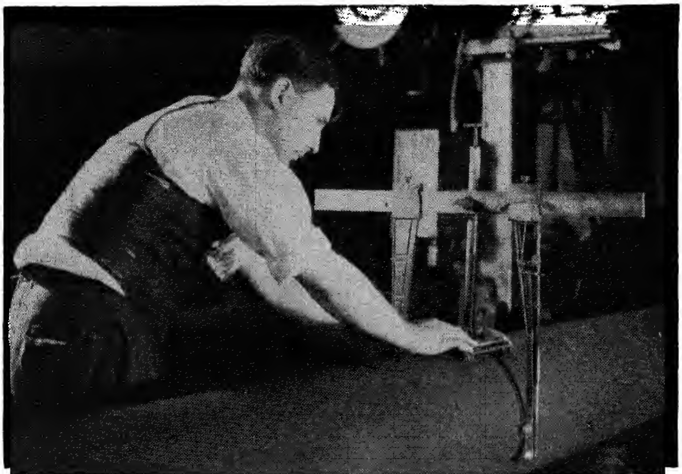


FIG. 4. Using a special caliper to measure the crown of a rubber-covered paper-mill press roll.

parts of the roll surface and fed back and forth until the desired finish is produced. When regrinding used rolls, the finish wheel alone is usually adequate.

All rubber rolls are ground dry. When the roll surface is sticky, loading of the wheel may be prevented by dusting the rubber with tire talc or soapstone. A burlap bag makes a handy container-duster.

When refinishing rolls that may have picked up kerosene or other chemicals, the regrinding should be started very carefully and slowly to prevent wheel loading and possible igniting of the covering. The wheel should be fed in very lightly until the entire roll surface has been cleaned up.

FOR A HIGH FINISH. Polish the roll with emery or other abrasive cloth while it is driven by a high-speed lathe. Maintain uniform pressure to prevent ridges and low places. Number 1 or 1½ coated abrasive may be used for preliminary polishing; No. 0 for finishing.

Grinding Vulcalock Rolls. More time and care are required to produce a smooth and uniform surface on the tough, resilient rubber than with other types of rubber covering. Extra grinding time is more than balanced by the longer periods between grinds.

Grinding-wheel Note. The foregoing suggestions concerning wheel grit, etc., are intended only as general guides, and it may be necessary to vary them because of conditions affecting wheels and machines. When difficulty is being encountered, grinding-wheel manufacturers should be consulted.

The Carborundum Company suggests the following gradings for abrasive wheels used for roll grinding:

Table 3

	Wheel
Hard-rubber rolls:	
Roughing	Silicon Carbide Brand Resinoid RC36-N7-B8
Roughing.	Silicon Carbide Brand Vitrified C365-I8-VW
Finishing.	Silicon Carbide Brand Resinoid RC80-L6-B8
Finishing.	Silicon Carbide Brand Vitrified C60-I8-VW
Soft-rubber rolls:	
Roughing	Silicon Carbide Brand Resinoid C12-L-B
Finishing....	Silicon Carbide Brand Resinoid RC36-L6-B8

Large paper-mill rolls (rubber), using a wheel 18 by 2 inches, etc.:

Table 4

	Hard rubber	*Soft rubber*	*General-purpose rough—all rubber*
Silicon Carbide Resinoid	RC36-N7-B8	C12-6-B	RC36-N7-B8
Silicon Cardide Resinoid ..	RC54-N7-B8	RC24-L6-B8	
Silicon Carbide Resinoid	....	RC36-N7-B8	

For general-purpose grinding of soft-rubber rolls such as typewriter platens, Carborundum Brand Silicon Carbide Resinoid RC36-L6-B8 is recommended.

The foregoing recommendations are to be considered as general. Often special gradings are required to meet varying machine conditions, operator's technique, etc.

Wormed Coverings

Felt-carrying Rolls. Some of the rolls used to carry felt on paper-making machines are "wormed," *i.e.*, provided with spiral ridges, so they will keep the felt smooth by exerting a stroking action.

Single worms, the most common type, start at one point in the middle of the roll and spiral in opposite directions to the ends, like right- and left-hand threads.

Double worms (rarely used): Two separate sets of worms starting 180 degrees apart and continuing to roll ends, with uniform separation.

Triple worms (even rarer than double): Three sets of spirals starting 120 degrees apart.

Worm pitch, for single worm, is measured from center to center of worm in a line parallel to roll axis. Pitch may vary from center to ends, to give varying stroking action.

In shape, the worm is a half oval. Dimensions of various typical worms are shown in Table 5.

TABLE 5. WORMED FELT-CARRIER ROLLS

Worm size, in.	Worm dimensions, in.		
	A	B	C
1 × 1/8	1.000	0.109	0.140
1 × 3/16	1 000	0.156	0 203
1 1/4 × 3/16	1 250	0.156	0 203
1 1/4 × 1/4	1.250	0.219	0.281
1 1/2 × 3/16	1.500	0 156	0 203
1 1/2 × 1/4	1.500	0 219	0 281
1 3/4 × 3/16	1.750	0 156	0 203
1 3/4 × 1/4	1.750	0 219	0 281
2 × 3/16	2.000	0 156	0 203
2 × 1/4	2.000	0 219	0 281

SQUEEZE ROLLS. Wormed top squeeze rolls of Vulcalock construction have a solid rubber-base cover 1/4 inch thick with worms 3/8 inch high. Usually stock of 83 to 97 density is used. The roll is ground to make the tops of worms even and concentric with the journals.

Pitch of worms on squeeze rolls is expressed in twelfths of a turn, *e.g.*, 6/12 of a turn, meaning that spiral makes one-half turn from center to end of roll. Usually the spiral is less than one turn.

Spacing of worms is determined by measuring the shortest line from edge of one worm to nearer edge of next; this measurement is *not* made parallel to core axis. Spacing should be slightly less than or equal to the width of the worms—never greater.

Roll Balance

Balance. Because of high paper-machine speeds, all rolls must be balanced to decrease vibration. Good balance, plus ball or roller bearings, gives maximum roll performance. Vibration from unbalance shortens rubber-covering life and damages bearings and other parts of the machine. All new rolls are balanced as a matter of manufacturing procedure, and old ones sent to the factory for recovering are checked for balance.

Static Balancing. This is used chiefly for rolls operated at less than 800 surface feet per minute. The roll, resting on parallel knife edges or knife-edged rollers, is turned slowly. It will come to rest with the heaviest portion downward. Babbitt is poured either around the lugs close to the spiders or into holes drilled for the purpose, to counteract the heaviness. Large press rolls are balanced within a limit of 5 pounds, while light steel-tube table rolls are balanced within a limit of a few ounces.

Dynamic Balancing. This is used for rolls operated at more than 800 surface feet per minute. One method is to mount the roll on ball bearings and drive it with a belt passing around the roll's circumference. Speed is approximately the same as service speed. Unbalance causes wobbling or oscillating. Holes are drilled in the region of maximum oscillation and babbitt poured to cancel the unbalance. For maximum smoothness of operation, a roll should be balanced dynamically at operating speed; "satisfactory" static balance is no indication that the roll will be dynamically balanced, particularly at high speeds.

The rubber cover of a press-roll core that is out of balance may develop a flat spot across the face or separate from the core. This is also true if the top roll is out of balance.

To calculate surface feet per minute:

$$\text{Sfpm} = \pi dn$$

where d = roll diameter in feet
n = number of revolutions per minute
Sfpm = fpm of paper sheet through machine

If the roll is crowned, measure d at the end.

Machine Drive. Maximum press-roll life results when a paper machine has sectional electric drives. Gearless, direct belt drives are easy on rolls, but worn gears and loose clutches result in roll damage and rapid wear. High roll pressure, produced by heavy weights on the compound levers, causes rapid crown wear, necessitating frequent regrinding. More grinding is required when machines operate at greater than 700 feet per minute than when the speed is slower.

TABLE 6. WEIGHTS, VOLUMES, ETC., OF LIQUID PULP STOCK, CARRYING VARIOUS PERCENTAGES OF AIR DRY STOCK

Per cent or lb dry (air) stock per 100 lb liquid	*Lb. dry stock in 1 cu ft liquid*	*No. cu ft containing 1 lb stock*	*Lb dry stock in 1,000 gal liquid (U.S.)*	*No. U.S. gal containing 1 lb stock*	*Cu ft liquid per min per ton stock per 24 hr*	*U.S. gal liquid per min per ton a. d. stock per 24 hr*	*U.S. gal liquid per min per ton bone dry stock per 24 hr*	*Lb liquid per min per ton air dry stock*	*Lb of water per lb of air dry stock*	*U.S. gal water per lb a. d. stock*	*U.S. gal water per ton stock*
0 10	0 0625	16 0	8	119 55	22 22	166 2	185.0	1388 88	999 0	119 36	238,710
0 20	0 1250	8 0	17	59 77	11 11	83.1	92 4	694.44	499 0	59 5	119,996
0 25	0 1562	6 40	21	47 87	8.88	66 49	73 8	555.55	399.0	47 75	95,511
0 30	0 1875	5 33	25	39 9	7 41	55 41	61.6	462 96	332 33	39 78	79,553
0 33	0 2063	4 80	28	35 91	6 66	49 86	55 4	416 64	297 10	35 55	71,094
0 35	0 2187	4 57	29	34 2	6 35	47.50	52.8	396 83	284 71	34 08	68,154
0 40	0 2500	4 0	33	29 92	5 55	41 56	46 2	347 22	249 0	29 80	59,605
0 45	0 2812	3 66	38	27 43	4 94	36 94	41 0	308 64	221 22	26 48	52,955
0.50	0 3125	3 2	42	23.92	4 44	33 25	35 8	277 77	199 0	23 82	47,636
0 55	0 3437	2 91	46	21.76	4 04	30 22	33 6	252 52	180.82	21 64	43,284
0 60	0 3750	2 66	50	19 94	3 70	27 71	30 8	231 48	165.66	19 83	39,656
0 65	0 4062	2 46	54	18 41	3 42	25 57	28 4	213 68	152 85	18 29	36,569
0 70	0 4375	2 28	58	17 1	3 17	23 75	26 4	198 42	141 86	16 98	33,957
0 75	0 4687	2 13	63	5 96	2 96	22 16	24 6	185.18	132 33	15 84	31,678
0 80	0 5000	2 0	67	14 96	2 78	20 78	23 1	173 61	124 0	14 84	29,683
0 85	0 5312	1 88	71	14 06	2 61	19 56	21 8	163 40	116 65	13 96	27,922
0 90	0 5624	1 83	75	13 71	2.47	18 47	20 5	154 32	110 11	13 18	26,358
0 95	0 5937	1 68	79	12 61	2 34	17 50	19 4	146 19	104 26	12 48	24,958
1.00	0 6250	1 6	84	11 97	2 22	16 62	18 5	138 88	99 0	11 85	23,698
1 25	0 7812	1 28	104	9 57	1 78	13 30	14 8	111 11	79 0	9.45	18,911
1 50	0 9375	1 07	125	7 98	1 48	11 08	12 3	92 59	65 66	7 86	15,719
1 75	1 0937	0 91	146	6 84	1.27	9 50	10 5	79 37	56 14	6 72	13,439
2 00	1 250	0 80	167	5 97	1 11	8 31	9 23	69.44	49 0	5 86	11,729
2 25	1 4062	0 73	188	5 49	0 99	7 39	8.21	61 73	43 44	5 20	10,399
2 50	1 5625	0 64	209	4 79	0 89	6 65	7 39	55 55	39 0	4 67	9,335
2 75	1 7187	0 58	230	4 35	0 81	6 04	6 71	50 50	35 36	4 23	8,465
3 00	1 8750	0 53	251	3 99	0 74	5 54	6.15	46 29	32 33	3 87	7,740
3 50	2 1875	0 46	292	3 42	0 63	4 75	5 25	39 68	27 57	3 30	6,600
4 00	2 5	0 40	334	2 99	0 55	4 15	4.61	34 72	24 0	2 87	5,745
4 50	2 8125	0 36	376	2 74	0 49	3 69	.....	30 86	21 22	2 54	5,080
5.00	3 1250	0 32	418	2 39	0 44	3 32	......	27 77	19 0	2 27	4,536
5 50	3 4375	0 29	459	2 18	0 40	3 02	....	25 25	17 18	2 06	4,113
6 00	3 75	0 27	501	1 99	0 37	2 77	....	23 15	15 66	1 87	3,750
6 50	4 062	0 25	543	1 84	0 34	2 56	......	21 37	14 39	1 72	3,438
7 00	4 375	0 23	585	1 71	0 32	2 38	......	19 84	13 29	1 59	3,176
7 50	4 687	0 21	627	1 60	0 30	2 22	......	18 52	12 33	1.47	2,946
8 00	5 0	0 20	668	1 50	0 28	2 08	... .	17 36	11 50	1 37	2,748
8 50	5 312	0 19	710	1 41	0 26	1 96	......	16 34	10 77	1 29	2,578
9 00	5 625	0 18	752	1 37	0 25	1 85	.. .	15 43	10 11	1 21	2,416
9 50	5 937	0 17	794	1 26	0 23	1 75	..	14 62	9 53	1 14	2,278
10 00	6 25	0 16	835	1 20	0 22	1 66		13 89	9 00	1 08	2,150

STEEL-MILL ROLLS

Rubber-covered rolls used in the manufacture of steel strip and sheet in continuous electrolytic tin-plating machines, and in galvanizing plants are not crowned but are ground to uniform diameter throughout. The rubber stock may be light colored to prevent stains on products.

In a strip steel mill, rubber-covered rolls are used as conveyor and hold-down rolls in acid pickling tanks and as wringer rolls at tank ends

for removing excess pickling solution from the strip. In stainless-steel manufacture, rubber roll covering prevents the stainless alloy from touching ordinary steel or iron and eliminates scratching and other damage. Light-colored rubber stock is used for handling stainless steel to prevent marking.

Continuous electrolytic tin-plating machines use three types of rubber-covered rolls: (1) tension rolls to pull the sheet through the line, (2) wringer rolls to remove water and chemical solution from the plated surface; and (3) guide rolls, which act as deflectors in changing the direction of travel of the sheet. The rubber stock must not mark or discolor the tinned surface.

In galvanizing plants, rubber-covered rolls remove excess water from the surfaces of the iron sheets, after they have been cleaned, to hasten subsequent drying with hot air.

Rubber compounds used for covering rolls that handle metal sheets and strips must be designed to resist the cutting and tearing action of rough, sharp edges.

Other Types of Rolls

Textile Roll Coverings. Rubber-covered rolls are used in the cotton, wool, silk, and rayon industries and in handling newer types of synthetic textile materials. Roll coverings in this class usually are identified by placing the word "textile" after grade numbers.

Replacement roll coverings are usually made to a density duplicating that which has been giving successful service. Operating temperatures in which rolls will be used should be given the manufacturer so he will know what type of construction can be used. For example, Vulcalock rolls are suitable only when temperature is not over 180°F.

The following classifications may be used as a guide in specifying rolls for textile uses, especially when there is no information about past performance:

Table 7

Textile Use	*Pusey & Jones Density*
Washing machine, jig dye, or any other roll where very hard stock is desirable	0– 6
Dye pad, squeeze, scouring, soaper, carbonizing, starch mangle, etc., rolls	18– 50
Bleach house squeeze, Tommy Dodd Backfill Mangle, and other medium-density requirements	40– 67
Squeeze rolls and any soft-density requirements	63– 97
Tommy Dodd Backfill Mangle, slap padder, three-roll quetch rolls	115–130
Slasher rolls	180–220
Any extremely soft requirements	210–240

Tannery Roll Coverings. All tanning-industry rolls require non-staining cover compounds. Roll-covering density suitable for different applications is given in Table 8.

Table 8

Tannery	Pusey & Jones Density
O'Keefe degraining, buffing machine rolls	83–97
Setting machine, refleshing machine rolls	115–130
Fleshing, unhairing, dehairing rolls	180–220 240–270
Splitting machine rolls	210–240

Table 9. Roll Diameter Tolerances

	Inch
Large rolls, normal tolerance	$\frac{3}{32}$
Large rolls, special tolerance	0 020
Table rolls up to and including 5 in. diameter	0 010
Table rolls over 5 in. diameter	0.020

Table 10. Types of Roll-covering Compounds

Paper mill	Crude-rubber or GR-S
Paper mill couch Steel mill Textile Tannery	Crude-rubber or Neoprene

Table 11. Roll-covering Hardness Range

Steel mill	*Pusey & Jones density*	*Durometer*
Wringer and hold-down rolls in continuous pickling	80–90	60
Steam scrubber (galvanizing) rolls	115	55
Tension (tinplating) rolls	80–90	60
Deflector or guide (tinplating) rolls	45	75–80

USEFUL INFORMATION—WATER

1 cubic inch weighs 0.0361 pounds.
1 pound = 27.7 cubic inches.
1 cubic foot = 62.4245 pounds at 39°F = 7.48 gallons U.S. = 6.2321 gallons imperial.
1 gallon U.S. = 8.33111 pounds = 231 cubic inches = 0.13368 cubic feet.
1 imperial gallon = 10 pounds at 62°F = 277.274 cubic inches = 16046 cubic feet.
1 pound pressure = 2.31 feet height.
1 foot height = 0.433 pounds pressure.

To convert imperial gallons into U.S. gallons, multiply by the factor 1.2; to convert U.S. gallons into imperial gallons, multiply by the factor 0.8333.

TABLE 12. POUNDS OF WATER EVAPORATED PER POUND OF DRIED PAPER

$$W = \frac{M_1 - M_0}{100 - M_1}$$

Per cent moisture in sheet entering driers	*Per cent of moisture in dried sheet*					
	5	*6*	*7*	*8*	*9*	*10*
60	1 375	1.350	1.325	1.300	1 275	1 250
61	1 435	1.410	1.385	1.365	1.335	1.310
62	1.500	1.475	1.450	1.420	1 395	1 370
63	1 565	1.540	1.510	1.485	1.460	1 435
64	1.640	1.610	1.585	1.560	1.530	1 500
65	1.715	1.690	1.655	1.630	1.600	1 575
66	1.795	1.765	1.735	1.710	1.680	1 650
67	1.880	1.845	1.820	1.790	1.760	1 725
68	1 970	1.935	1.910	1.875	1.845	1 810
69	2.062	2.030	2.000	1.970	1.935	1.900
70	2 163	2.140	2.100	2.07	2.04	2.00
71	2 280	2.245	2.210	2.170	2.140	2.100
72	2.390	2.360	2.320	2.280	2.250	2 22
73	2 520	2.480	2.440	2.410	2.370	2.34
74	2.650	2.620	2.580	2 540	2 500	2 46
75	2 800	2.760	2.720	2.680	2.640	2 60

W = pounds water evaporated per pound dried paper
M_1 = per cent moisture in sheet entering driers
M_0 = per cent moisture in dried sheet

TABLE 13. CROWN CONVERSION TABLE FOR PAPER-MACHINE PRESS ROLLS

Vulgar fractions, circum. crown, in.	*Decimal fractions, circum. crown, in.*	*Crown diametral, in.*
3/8 or 6/16 = 0 375	375/1,000 =	120/1,000
5/16 = 0 3125	312½/1,000 =	100/1,000
¼ or 4/16 = 0.25	250/1,000 =	80/1,000
3/16 = 0.1875	187½/1,000 =	60/1,000
⅛ or 2/16 = 0.125	125/1,000 =	40/1,000
1/16 = 0.0625	62½/1,000 =	20/1,000
1/32 = 0.03125	31¼/1,000 =	10/1,000
1/64 = 0.015625	15⅝/1,000 =	5/1,000

Chapter 20

SPONGE RUBBER

Sponge rubber falls into two classes: (1) milled sponge, including hard and soft types, and (2) latex sponge, soft only.

Milled Sponge Rubber

This type, also known by such names as press-cured, chemical, chemically blown, and mechanical sponge, is made in very much the same manner that a baker makes light bread. The compound, either crude or American rubber, is milled to mix the ingredients, which include an expanding agent like sodium bicarbonate (the same baking soda the baker uses). The mix is extruded or otherwise processed to convert it into shapes that will fit mold cavities. Under heat of molding, the sodium bicarbonate decomposes into carbon dioxide gas, which expands and causes the rubber to fill the mold cavity. The spongy structure results from the creation of individual pockets of gas while the compound is still plastic. In chemically blown sponge, the cells are not all interconnected as they are in foamed latex. Nearly all milled sponge rubber is processed by molding, although some products such as bath sponges are made by open steam curing, the sponge compound being placed in pans—again like the baker's bread!

Soft Chemically Blown Sponge. The kinds of rubber that have been used for making chemically blown sponge include crude, GR-S, reclaim, and Neoprene. These rubbers are ordinarily made into soft-rubber sponge, although rubbers other than Neoprene can be made into hard sponge if desired.

Density. A characteristic of milled sponge rubber is that its density varies with its thickness, the density of thin sheets or sections being greater than that of thicker sheets or sections. There are two reasons for this: (1) The surfaces of a sponge sheet or slab cured either in a mold or in the open have a skin composed of rubber that is relatively free of openings or pores and therefore is more dense than the rest of the piece. In a thin section, the two skin surfaces represent a greater percentage

of the total weight per unit volume. (2) The action of the expanding agent produces a fluffier sponge in large thicknesses than in thin sections.

For nearly all purposes, it is sufficient to classify milled sponge into three densities: soft, medium, and firm.

Table 1 shows how various kinds of sponge rubber vary with respect to density and thickness. Note that the thicker sections exhibit lower density.

TABLE 1

Kind of rubber	*Density classification*	*Thickness, in.*	*Weight, oz/in.³**
Neoprene	Soft	1/8	0.30
	Soft	1	0 16–0 17
	Medium	1/8	0.34
	Medium	1	0.22
	Firm	1/8	0 35
	Firm	1	0.28
GR-S	Soft	1/8	0.27
	Soft	1	0 19
	Medium	1/8	0.30
	Medium	1	0.21
	Firm	1/8	0 34
	Firm	1	
Reclaim	Soft–medium	1/8	0 42
	Soft–medium	1	0 24

* Within ±0.04 to 0.05 ounces.

USES OF MILLED SPONGE RUBBER. This versatile product is used as a mounting or cushioning material for absorbing vibrations or shock; as a sealing agent against air, moisture, sound, and dust or dirt of all sorts; as a filler; as an absorber of water and sound; and as a thermal insulator. It is used for making automobile arm rests, gaskets, kneeling pads, cushions, bumpers, stamp-pad cushions, bushings, heel pads, upholstery padding, mounts for electronic-instrument parts, bath sponges, toys, moistening pads for stamps and envelopes, special applicators for liquids, and earphone pads. Many of the gasket applications are on automobiles and include cowl ventilator, door, and trunk compartment seals.

PROPERTIES AND DESIGN NOTES

Manufacturers of sponge-rubber products have noted a tendency for designers and other users to overspecify. In most of the applications, sponge is used merely as a cushioning material or a seal to compensate

for some shortcoming in metal or other assemblies, and frequently rigid specifications are not necessary because there are no critical conditions to be met. Whenever possible, the best plan is for the customer to specify only whether the sponge is to be soft, medium, or firm; explain the use to which he expects to put the material; and then let the manufacturer take care of the remaining details. Specification of load-deflection requirements, when tolerances are too tight, threatens to become an expensive practice. When not absolutely essential, load-deflection specifications should be omitted, for they can increase the product cost.

Tensile Strength and Elongation. Although these two properties are often considered highly important when solid-rubber products are being used, they are of negligible importance in the case of sponge rubber—which is nearly always used for its cushioning or compression properties.

Aging, Heat Resistance, Acid Resistance, etc. Such properties in sponge rubber are comparable to the same properties in solid rubber of like composition. However, because of the cellular structure of all types of sponge and therefore the greater exposed surface, aging reaction to solvents, etc., are generally more rapid than with solid rubber, whose total surface per unit volume is considerably less.

Neoprene Sponge Resistance. This oil- and heat-resisting material is preferable where there must be resistance to fats and oils of mineral, animal, and vegetable origin; to aromatic hydrocarbons such as benzol; to metallic soaps used as printing-ink driers; and to other materials and conditions as given in Chap. 2.

Shapes and Sizes. Milled sponge rubber, besides being made in innumerable molded shapes to meet customers' needs, is normally available in the following forms:

Slabs. Sheet or slab sponge rubber is employed when the user desires to cut his own gaskets or other parts. Thicknesses range from 1/8 to 1 inch. Standard slab sizes include 24 by 120, 24 by 60, 24 by 24, 20 by 120, and 20 by 20 inches. The slab may be "skinless" or have skin on one or both sides.

Tubing. This is a useful form where the rubber is to be slipped over a straight or curved pipe or other part to serve as a cushioning or insulating (thermal) material where rigid covering would be difficult or impossible to apply.

Cord. This useful form is made in continuous lengths in diameters of 3/16, 1/4, 5/16, 3/8, and 1/2 inch. Diameters larger than these are available in shorter lengths. This form is used principally for seals, shock absorbers, windlace, and gaskets.

Cost. Prices are always subject to variation, and predictions cannot be made about the future cost of American-made rubbers in relation to crude and reclaimed types. However, American-rubber compounds have been more costly than other kinds.

Cost of molded sponge articles is influenced by the difficulty of molding, percentage of waste or loss, and rigidity of specifications.

Cementing. The same adhesives are used for sponge-rubber compounds as for corresponding solid-rubber materials, as described in Chap. 3. Often the cost of a combination sponge- and solid-rubber product (such as an earphone pad) can be lowered considerably by cementing the two materials together after curing instead of uniting them during molding.

Appearance. Milled sponge-rubber articles cannot be judged, especially as to appearance, on the same basis as solid-rubber products. Generally the sponge piece is covered by fabric or solid rubber or is concealed by parts of an assembly, so that its appearance is of no importance. It is characteristic of sponge rubber that the skin forming its surface often is marked with irregularities known as flow cracks—so named because they occur during flowing of the compound while being cured. These cracks seldom if ever affect the usefulness of the piece. A dusty surface is another common characteristic of sponge because it has to be dusted with powdered soapstone or mica during manufacture. This dust can be removed only partially; but since the sponge is covered or concealed anyway, dustiness is seldom objectionable except, perhaps, in delicate equipment where any dusty material might be a hazard. Designers can save a lot of expense by not insisting upon needless freedom from flow cracks or dusty surfaces.

Combinations with Solid Rubber. Some products are formed by curing sponge-rubber and solid-rubber compounds together in a mold, the solid material forming a cover for the sponge. Often the same ends can be accomplished at less expense by curing the solid and sponge parts separately and then cementing them together or fastening them with clips or other means.

Tolerances. Dimensions are more difficult to hold within specified limits when sponge rubber is the material than when solid rubber or rubberlike plastics are being processed. Whenever possible, the maximum tolerance freedom should be given the manufacturer. Thickness tolerances may be as follows:

$\frac{1}{8}$-in. thickness	± 0.015 in.
Greater (to 1 in.)	$\pm \frac{1}{32}$ in.

"Picture Frame" and Notched Gaskets. Sponge-rubber gaskets shaped like a picture frame are among the most widely used products. They are molded in one piece and have no seams or joints. Sponge-rubber strips notched and bent into rectangular or other shapes are replacing molded gaskets in many applications. Wherever a bend or corner is to be made, a notch is formed by two 45-degree cuts (90-degree included angle) extending halfway through the strip. A corner formed by bending at this notch has a rounded outer radius but is square on the inside. For large-radius bends, several closely spaced notches may be made, their angles being in proportion to the degree of bending.

Edges. Sharp or feathered edges should be avoided. It is difficult or impossible to make the compound fill the mold completely along such edges.

Thickness. The normal range of milled sponge thickness is from ⅛ to 1 inch. Thinner sections than ⅛ inch can be produced by splitting.

Best Dimensions. Milled sponge compounds are easiest to mold when the product thickness is around ½ inch.

Nitrogen-blown Sponge

A material similar to ordinary chemically blown sponge rubber is known as nitrogen-blown sponge because nitrogen gas is used to form the bubbles. The material is also known by such other names as flotation sponge. The bubbles or pockets dispersed throughout the material are not connected with each other as in latex sponge. Consequently, there is no water absorption, which makes this sponge useful for various kinds of flotation service.

Soft Nitrogen-blown Sponge. This is similar to ordinary milled sponge in appearance. When compressed, the nitrogen gas imprisoned in the innumerable isolated cells produces a pneumatic cushioning action distinct from the action of the rubber compound itself. This type will not absorb water. The material is suitable for such purposes as making football clothing and other athletic padding.

Hard Nitrogen-blown Sponge. This is a true hard rubber having a spongy structure produced by the inclusion of nitrogen gas bubbles. It is bone hard, of low weight per unit volume, and quite brittle. Electrical insulating properties are excellent. It is a good thermal insulator, its coefficient of heat conductivity, in English units being about 0.30. Soft sponge rubber ranges from about 0.41 to 0.65. The density of hard sponge ranges upward from about 2 pounds per cubic foot. Dimensions of single pieces are limited by manufacturing or handling equipment.

Applications. It is suitable for marine life rafts and floats; as insulation for electronic equipment, especially air-borne types; as a plying

material with sheet metal for light, strong structural members; as floating covers for chemical tanks; and for fish-net floats. In some of these applications, there are factors that have limited the usefulness of this material. For example, fish-net floats performed satisfactorily, but it was

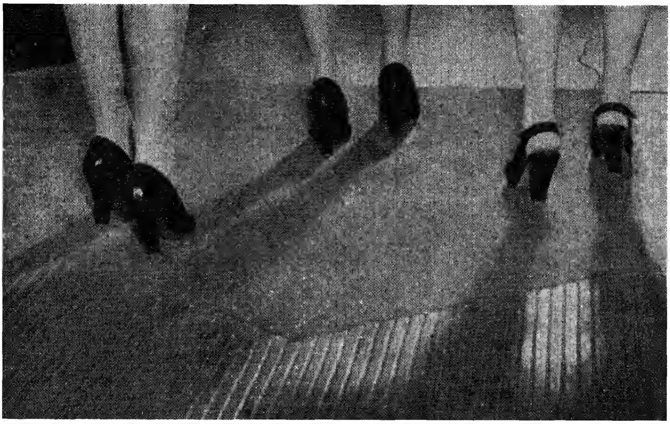


FIG. 1. The floor shown is covered with a 9/16-inch-thick test piece of lightweight airplane flooring made by sandwiching a core of hard-rubber sponge between metal sheets.

found that the rubber was damaged by hot tars applied to the nets as preservatives. Improved net treatment to eliminate the tarring treatment would make rubber floats practical.

The use of hard-rubber sponge as a thermal insulating material has not been widespread because of its high cost in relation to other insulators of equivalent efficiency. For comparison, the coefficients of heat conductivity (English) for some materials are

Hard sponge	0.30
Cork, no binder	0.25
Glass wool	0.29
Wool felt	0.47
Soft-rubber sponge	0.41–0.65
Sawdust	0.35
Asbestos sponge felt	0.423
Rock wool	0.26

Latex Rubber Sponge

This type of sponge rubber is made by different manufacturers and marketed under various names such as Airfoam, Air-Cell, and Latex Foam.

This time, instead of using bread-baking methods, the manufacturer borrows another idea from the kitchen and whips liquid latex, which

contains necessary compounding ingredients in addition to the rubber hydrocarbon, until a whipped-creamlike foam is produced. This is placed in molds and vulcanized or is cured by open heating. The resulting sponge has the following characteristics:

Is extremely soft and resilient.

Is about 90 per cent air, 10 per cent rubber.

Has about 250,000 air cells per cubic inch.

Air cells are interconnecting, in contrast to the isolated cells of other types of sponge.

Forms a "skin" only when cured in contact with polished aluminum or other surface. This skin is porous.

TABLE 2. LATEX RUBBER SPONGE

Grade	*Lbs required for 25% compression on Scott tester*	*Weight of 1 cu in., lb*
Extra soft.......	5–10	0.003
Soft............	10–25	0 004
Medium	25–40	0 005
Firm...	40–85	0 006

Is an excellent shock and vibration absorber.

Is not attacked by mildew, vermin, moths.

When soiled, is easily washed and sterilized.

Has no obvious rubber or other kind of odor.

Is lighter and stronger than ordinary sponge rubber and finer in texture.

Does not pack, sag, or develop pockets or lumps.

Indicated service life in most applications is 10 to 15 years and sometimes longer.

Does not produce a lint or dust.

In most applications, the sponge should be covered with fabric or other material, especially when made of crude rubber, to protect it from sunlight damage.

Any crude- or American-rubber latex may be foamed, although some are more difficult than others. Nonrubber synthetic materials also hold promise of lending themselves to similar treatment. Materials that have been used for making latex sponge include GR-S, Nitril, Neoprene, and crude rubbers or combinations of these.

Latex sponge is graded according to its softness as Extra Soft, Soft, Medium, and Firm. In determining these grades, a Scott testing machine

having a disk-shaped indentor of 50-square-inch surface is used, and the weight required to compress the material 25 per cent is determined. Table 2 is based on recommendations of the Rubber Manufacturers Association, Inc.

Latex sponge is manufactured in solid and cored slabs of various thicknesses and sizes. Maximum sizes are limited by the manufacturing equipment available and by convenience in handling by workmen. Some of the standard maximum slab sizes produced by different manufacturers are

42 by 53 inches
40 by 54 inches
30 by 104 inches
30 by 108 inches

On the basis of thickness, common products may be grouped as follows:

Solid sheets up to 1-inch thickness.

Cored utility material including upholstering topper pads, 1 to 3 inches. Used to cover tops of mattresses, upholstery springs, automobile seat cushions.

Thick molded cushions such as mattresses and transportation equipment seating using no metal springs.

CEMENTING. Size limitations of single pieces are of no particular concern because of the ease with which latex sponge can be cemented. The same kinds of cements are used as for solid-rubber articles, each adhesive being selected according to the kind of rubber compound used—Neoprene, crude rubber, etc. Wherever a cemented seam occurs, the density of the material is greater and flexibility is less. In order to prevent objectionable ridges on the surfaces of mattresses, cushions, and other products, it is a desirable practice to run the cement only to within about ⅛ inch of the edges of the areas to be joined (surface of finished article).

TOLERANCES. Standard tolerances have been set up by the Rubber Manufacturers Association (see Table 3).

CUTTING. Latex sponge rubber is easily cut with scissors, band saw, knife and straightedge or with clicker dies where production is in quantity.

APPLICATIONS. Transportation seating, including railway, automobile, bus, airplane, and marine, has adopted latex sponge universally as a seat-cushioning material. It is used widely for domestic and office furniture. Mattresses made of the material have met with large success in homes and institutions; in hot climates, the sponge has proved to be cooler than other materials because of its air-cell construction. Medical applications include fracture pads and various other cushioning devices.

Miscellaneous applications include the use of latex sponge for cushioning delicate instruments against shock and vibration.

UPHOLSTERING. Any upholsterer having a supply of solid and cored latex sponge slabs, suitable cement, and tacking tape can work the material without special experience or extra equipment. In general, densities should be selected as follows:

Soft: 1¼ inches thick, for furniture, automobile seat backs, wrapping around box-spring reversible cushions.

TABLE 3. LATEX-FOAM TOLERANCES

	Thickness, in.	Tolerance, in.		Length and width, in.	Tolerance, in.	
		Plus	*Minus*		*Plus*	*Minus*
Cored	0–3	1/8	1/16	0–6	3/16	1/16
	3–5	3/16	1/8	6–12	3/8	1/8
	5 and over	1/4	3/16	12–24	1/2	1/4
				24–36	5/8	3/8
				36–48	3/4	1/2
				48–60	7/8	5/8
				60–72	1	3/4
				72 and over	1 1/8	7/8
Uncored	1/4–3/8	1/8	1/16	0–6	5/16	1/16
	1/2–5/8	1/8	1/8	6–12	1/2	1/8
	3/4–1	3/16	1/8	12–24	11/16	1/4
	1¼ and over	1/4	3/16	24–36	7/8	3/8
				36–48	1 1/16	1/2
				48–60	1¼	5/8
				60–72	1 3/8	3/4
				72 and over	1½	7/8

Soft: 4½ inches or more thick, for extreme-comfort furniture cushions, the sponge being used over spring base that has a 2½- to 3-inch latex sponge decking over springs.

Medium: 2 to 3 inches thick, for heavy-duty transportation seats and factory seat backs and for spring decking in studio couches and davenports.

Medium: 2½ to 3 inches thick, for decking over spring base; 4½ to 6 inches thick, for seat cushion itself.

Firm: for severe-service applications such as railroad engine cabs, heavy trucks, severe-service factory seating. Full-molded cushions are being used widely in such service.

SEAT STANDARDS. Furniture and seat-equipment manufacturers and the Rubber Manufacturers Association have worked out a series of

standard molded cushion sizes for theater, furniture, and transportation equipment seats that are used without springs. Some RMA sizes for furniture cushions are shown.

Some density classifications for molded cushions are

Soft: Reversible furniture cushions, bus and railway back-rest pads, special molded furniture seat pads.

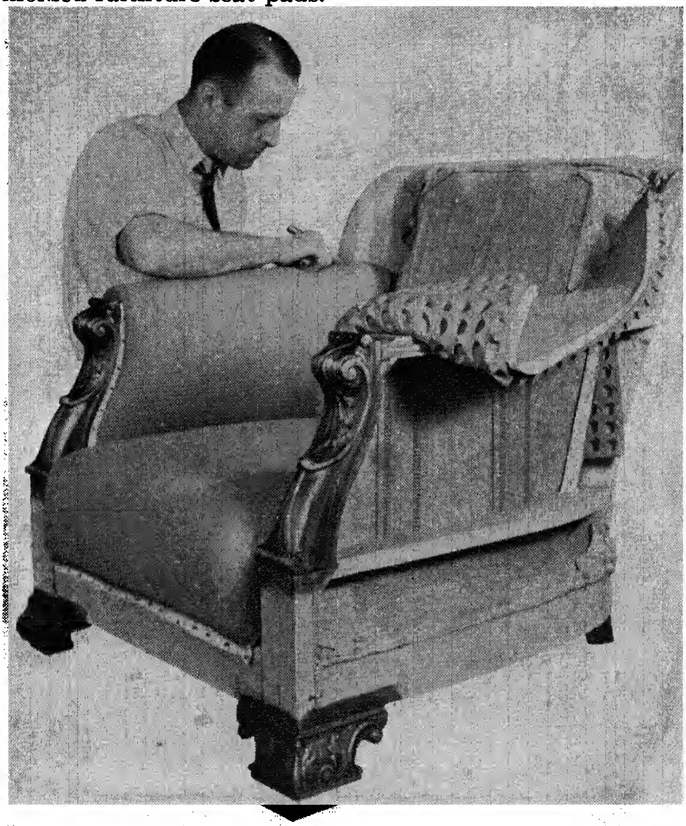


FIG. 2. Upholstering a chair in which latex foam, a form of sponge rubber, is the cushioning material. The rubber cushioning elements may be either molded to shape or made from flat slabs that are easily shaped as desired.

Medium: Special molded back rests for severe service in transportation equipment, molded seat cushions for light-service bus and railroad equipment.

Firm: Special-service bus seats, engine-cab seats, heavy-duty truck seats.

MOUNTING CUSHIONS. A general practice is to fasten the cushion to a plywood slab having the same contour. The slab must be drilled with

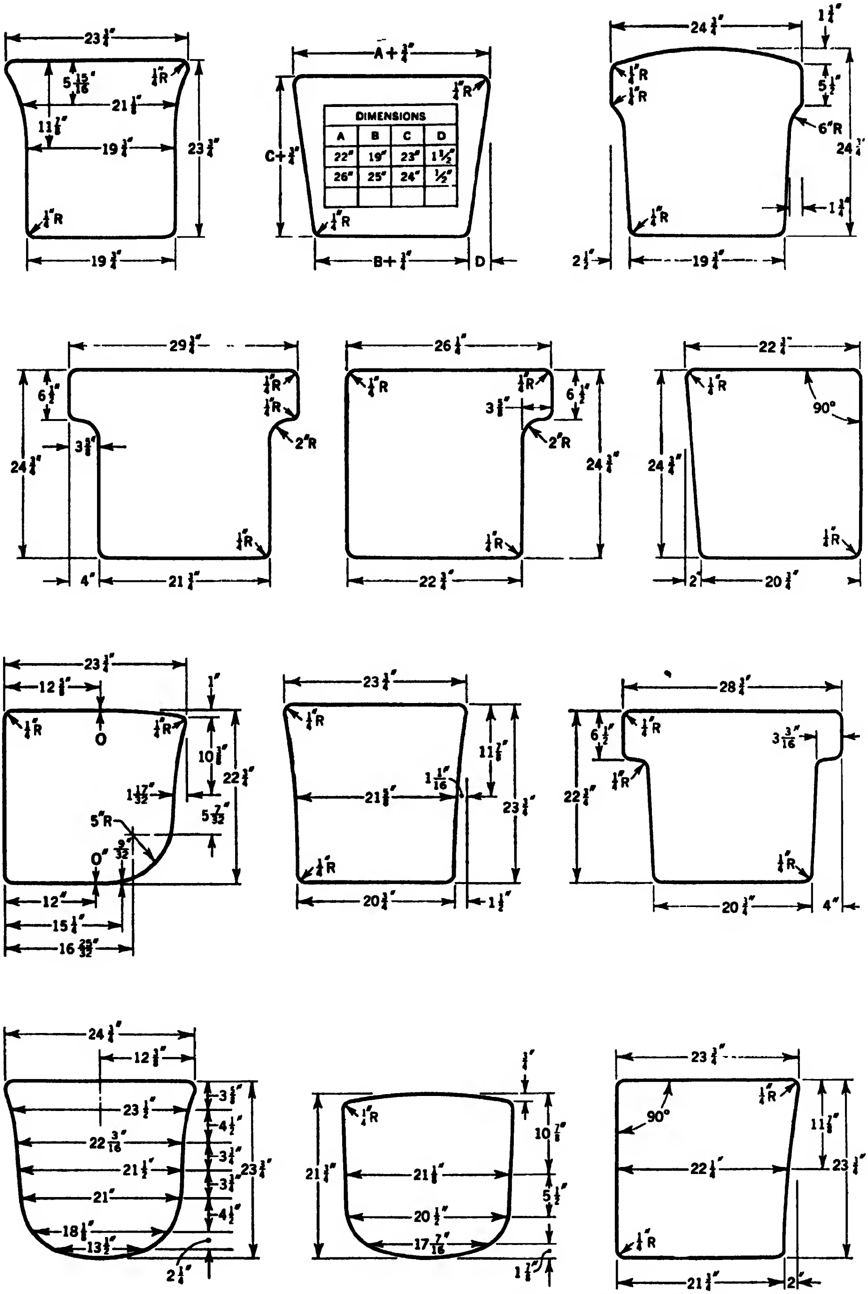
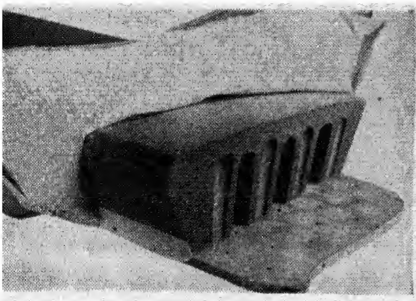


Fig. 3. Shapes and dimensions of 12 molded sponge-rubber (latex-foam) cushions used in upholstering furniture.

enough ¼-inch holes to provide free air passage to 75 per cent of the cored cushion cavities. Tacking tape 2 inches wide is cemented around the cushion so 1 inch extends below for tacking to the edge of the plywood. Covers are made in the usual manner but must be sized and fastened with sufficient initial tension to allow for cover stretch and to



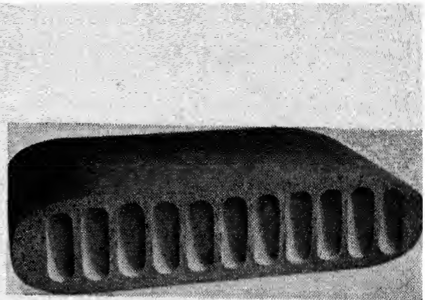


FIG. 4. A molded latex-foam seat cushion of the type used in automobiles and other vehicles, showing method of mounting on a perforated plywood base. The ¼-inch holes should be placed to vent 60 to 75 per cent of the cored cushion cavities. The cover material is brought down and tacked to the base.
FIG. 5. A standard reversible latex-foam furniture cushion made by cementing together two half sections.

produce maximum neatness. Leather should be selected and tanned especially for latex cushions and should have a minimum stretch and a minimum weight of 3½ ounces. Soapstone should be dusted between cushion and cover.

Cushion Crown. For leather and imitation leather, the crown should be at least ⅝ inch. Table 4 gives the dimensions of crowns for bar and restaurant stool cushions.

TABLE 4

Thickness, in.	*Diameter, in.*	*Crown, in.*
2	13	⅜
3	13	⅜
2¾	14	1½

Reversible Cushions. These are made by cementing two cored cushion slabs together so the cores match to form closed cavities.

Chapter 21

RUBBER THREAD AND TAPE

Rubber thread is vulcanized rubber of high elasticity, in the form of a strand having approximately equal thickness and width.

Rubber tape for textile use is of two types: (1) the same material as that used for thread, in the form of a strip whose width is appreciably

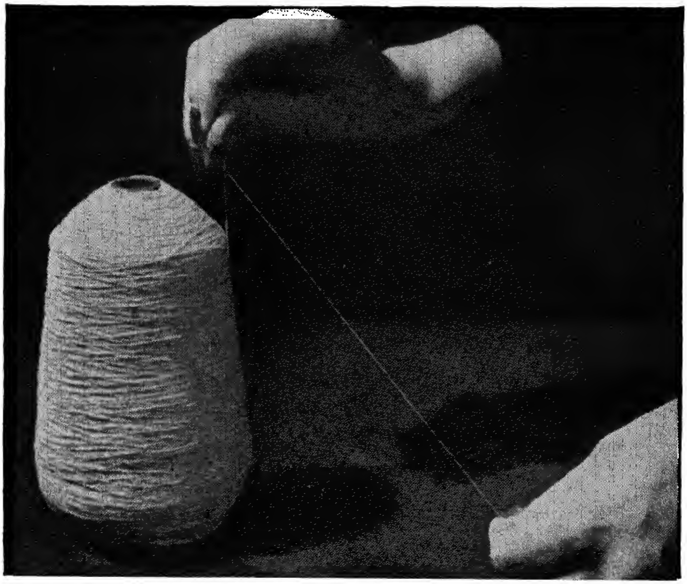


Fig. 1. Rubber thread that has a textile covering can be stretched only as far as the cover strands permit.

greater than its thickness, and (2) covered or naked rubber thread braided or woven into a round or flat section.

Elastic rubber thread and tape are made from high-modulus, pure gum compounds and are examples of the highest types of rubber materials in common use.

Types of Thread

Cut Thread. A widely used method of making thread is to cut calendered sheet into strands that are approximately square in cross section. This method of manufacture is not restricted by patents.

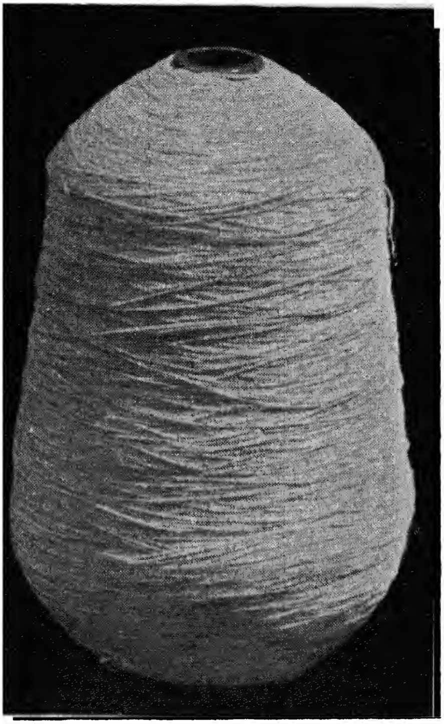


Fig. 2. Cotton-covered rubber thread, which can be woven into elastic bandages and a considerable variety of other products.

Latex Thread. By various patented processes, rubber thread is made from latex. Principal types are

1. Extruded thread having circular cross section (U.S. Rubber Company).
2. Thread having a ring-shaped cross section, being, in fact, very slender tubing (Firestone Tire & Rubber Company).
3. Thread having a cross section shaped like an hourglass. This results in the thread's being compressed when covered with textile strands or woven together with rayon, cotton, and other filament materials, etc. The expanding tendency of the compressed rubber produces a gripping action between the thread and textile fibers combined with it, thereby reducing slippage (B. F. Goodrich Company).

Types of Tape

Cut Tape. This is made by cutting sheet material of various thicknesses into ribbons of the required widths.

Braided Tape. This is rubber thread braided mechanically into flat or cylindrical tapes of various widths. The thread may be either bare rubber or rubber covered with cotton or other textile threads.

Woven Tape. This is similar to braided but is formed by weaving rubber threads into strips of various widths.

Some idea of the size in which tape can be made is given by the fact that the simplest machine may weave or braid only three strands into tape while the most complex loom can combine 6,000 strands into a single tape. Necessity of maintaining uniform tension on the strands in order to prevent flaws in the finished product is an indication of the precision with which rubber thread can be handled.

Technique of Handling

Rubber thread is put up on spools containing a single strand, on beams containing numerous strands side by side, or in chains containing specific or undetermined numbers of strands—the exact arrangement depending on the braiding or weaving machine that will process the thread.

Braiding Tension. When rubber thread is being braided into tape, each strand is elongated approximately 300 per cent. Over-all elongation of the tape is about 200 per cent. Thus, when the tape is relaxed, it possesses the required stretching capacity. Normally, rubber tape made by braiding or weaving will stretch 200 to 300 per cent, or the limit permitted by the textile thread covering.

Lubrication. No lubricant is used on rubber thread during braiding or similar processing. However, in hot weather, it sometimes is advisable to dust the threads with fine talc to prevent sticking.

Physical Characteristics

Tensile Strength. The most common range is from 2,000 to 3,200 psi of original cross section.

Elongation. Maximum elongation of bare thread or cut tape is from 500 to 900 per cent of original unstretched length, depending on requirements.

Gauge. The gauge of rubber thread is a figure indicating the number of strands that must be placed side by side to make 1 inch.

Cut Thread Gauge. Normal range is 24 to 120.

Latex Thread Gauge. Normal range is 36 to 120.

Cut Tape. Thickness range is usually 24 to 120 gauge (0.042 to 0.0083 inch). Width may vary over wide range.

LENGTH. *Cut Thread Length.* The length is limited by manufacturing methods to 80 to 200 yards.

Latex Thread Length. The length of this type is unlimited.

COLOR. The colors of American-rubber compounds used for thread and tape are limited to black and white. There is no limit for crude-rubber compounds, although some colors are unsatisfactory from a cost standpoint.

TOXICITY. Extensive research has failed to show that rubber thread, tape, or fabric made either from crude-rubber or from American-rubber compounds is toxic. However, there seem to be occasional persons who show an allergic reaction to rubber products of either type, just as there are persons who will react to numerous nonrubber materials.

APPLICATIONS

Some of the common uses of thread and tape are indicated in the following list. There are numerous possibilities for applying these materials in new ways and for solving new-product problems.

1. FLEXIBLE METAL TUBING. Bare rubber thread, usually 30 gauge, is combined by automatic machines with metal ribbon to form spiral, flexible tubing for carrying gases and liquids. The thread is under tension. The length of the thread limits the length of the tubing.

2. HEADBANDS. Woven elastic tape is used for holding goggles, face shields, and other protective devices on the heads of factory workmen and others. Such tape will last longer if it is not under tension when not in use. Thus, hanging goggles by their tape strips will shorten the rubber-thread life.

3. ENERGY-STORING DEVICES. Typical of this use is the combining of strands of cut rubber tape into model-airplane motors. Usually 30-gauge tape ¼ to ⅛ inch wide, made of high-modulus stock, is used. Similar applications in mechanical devices might be feasible.

4. SUSPENSIONS. Cables made of heavy-gauge rubber threads and covered with braided fabric formerly were used for shock-absorbing purposes on airplane landing gear. Similar applications might solve special problems, such as the suspension of instruments by rubber-thread cables or tapes. Such cables are stronger than solid ones and permit better control of elongation. Shock absorber cord is made in the following stock diameters: ⅛, 5/32, 3/16, ¼, 5/16, ⅜, ½, ⅝, and ¾ inch.

5. Clothing. Elastic thread and tape are incorporated into numerous articles of clothing, such as suspenders, sock tops, shoes, lingerie, girdles, suits, bathing apparel, and infants' wear. For applications such as hosiery tops, low-modulus rubber is used.

6. Medical. Fabric and tape made from elastic threads are used extensively in orthopedic devices, bandage units, etc. Crude rubber is generally preferable.

7. Specialties. An example is the use of fine rubber thread for making decorative lace, the elastic properties making possible a novel crinkled effect when the thread is woven under slight tension.

8. Golf Balls. A typical golf ball consists of pure gum rubber thread wound under tension around a core and provided with a tough cover. The thread is in reality a ribbon, typical dimensions being 0.022 by 1/16, 0.022 by 5/64, and 0.017 by 1/16 inch. The thinner ribbon makes a harder ball.

Chapter 22

MISCELLANEOUS RUBBER PRODUCTS

Pressure-sealing Zipper Fastener

The familiar slide fastener has been made gas- and liquid-tight. This was accomplished by adding to it a precision-molded rubber seal that opens and closes when the fastener does. The rubber lips overlap so tightly that the fastener will not let water, air, or other liquid or gas pass from the pressure side (see Fig. 1) at pressures ranging up to the maximum its structure will withstand. The fastener may be attached by

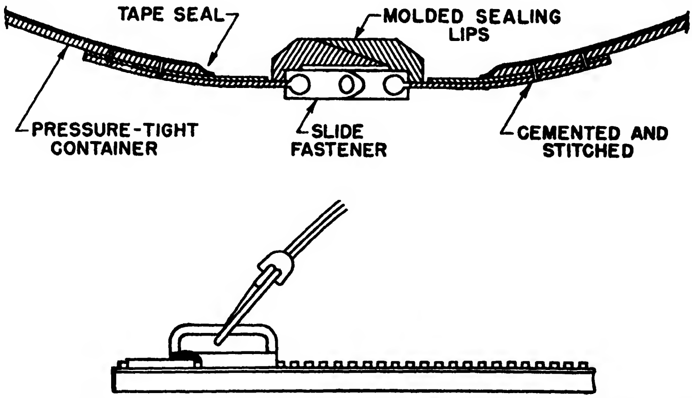


Fig. 1. Construction of a Pressure-sealing Zipper fastener. Pressure of a gas or liquid against the fastener forces the rubber sealing lips together.

stitching or cementing to such materials as fabric, sheet rubber or plastic, and metal.

Types. 1. *Separating.* This seals the entire length, but not at ends. The slider operates from either or both sides. A typical application is for fastening clothing (coats).

2. *Nonseparating.* This seals the entire length but is open at one end. The slider operates from either or both sides. A typical application is for tent closure.

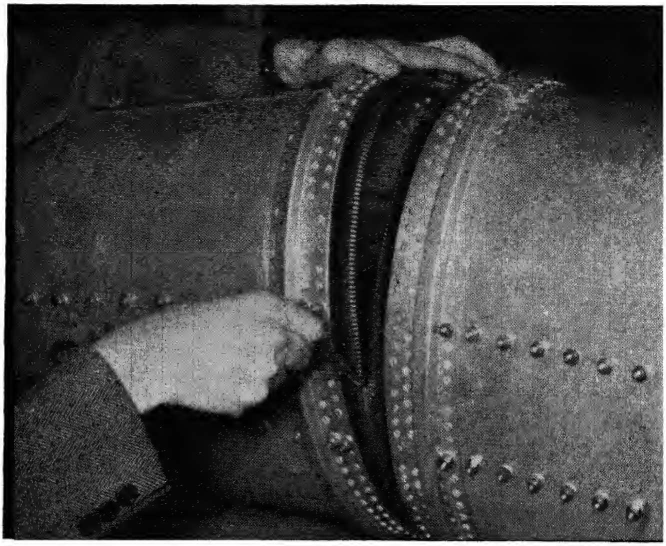


FIG. 2. A Pressure-sealing Zipper used for closing an air-duct joint. The rubber sealing lips are on the inside where pressure is higher.

3. *Nonseparating.* This seals the entire length and at both ends. The slider operates from either or both sides. A typical application is on tobacco pouches and vacuum-cleaner bags.

FIG. 3. The Pressure-sealing slide fastener used on this waterproof carrying case is a type that produces a tight seal at both ends of the opening.

SOME ADDITIONAL APPLICATIONS OF PRESSURE-SEALING ZIPPER. These include the following: nonleaking fastener for all waterproof clothing; air- and lighttight seal for darkroom tents without use of flaps; similar seal for photographers' changing bags; footwear of all kinds; luggage of numerous types; sporting goods such as golf-bag hoods, tennis-racquet cases; weathertight seals around windows and doors of vehicles; door or similar openings where dust, light, water, or air must be excluded, including those which must withstand a pressure differential; inspection openings, etc., in industrial equipment such as air-conditioning installations, high- and low-pressure ducts, and suction systems;

aircraft equipment; food bags for campers; bedroll bags; fumigation tents; waterproof cases for cameras and other optical equipment; desiccating chambers or containers for use in conjunction with dehydrating agents such as silica gel; mothproof bags; and cases and covers for electrical equipment.

The fastener is made in two sizes, as follows:

TABLE 1

Over-all width, in.	*Width of lips, in.*	*Thickness at lips, in.*
$2\frac{1}{16}$	$\frac{3}{8}$	$\frac{3}{16}$
$1\frac{5}{8}$	$\frac{9}{32}$	$\frac{1}{8}$

Other characteristics	*Talon Size 1-A*	*Talon Size 5-6*
Weight per foot, lb.	Approx. 0.15	Approx. 0.10
Minimum bending radius, in.	1.5	1.0
Lb pull to open or close	3.5 average	2.0 average
Maximum lateral strength, lb/in.	200	150
Maximum effective pressure, gas or liquid	Withstands pressure up to strength of basic fastener	
Temperature range, crude rubber	Withstands −70 to +180°F	
Temperature range, American rubber	Compounded to meet requirements	
Aging test	No change after 96 hr in oxygen bomb	
Endurance test	Operated satisfactorily after 10,000 open-and-close cycles	

Cutless Rubber Bearings

Cutless bearings are used as propeller shaft and rudder pintle bearings in commercial and naval vessels of any size, in centrifugal equipment such as condensate and circulating pumps, in deep-well turbine and other rotary-type pumps, in suction dredge cutterheads, as dredge propeller shaft bearings, on hydraulic power turbines having shafts as large as $37\frac{1}{2}$ inches in diameter, and on acid-tank and other classes of agitators, sand and gravel washers, and similar machinery.

Rubber bearings can be operated in any underwater location or where water can be piped to them, and in fluids, chemical or otherwise, not detrimental to rubber compounds. The coefficient of friction as deter-

mined in a properly lubricated cutless rubber bearing compares favorably with that in well-designed oil-lubricated bearings and is especially low with high shaft speeds. Because of the softness of the rubber compound, hard particles of dirt that work between the rubber and the shaft make depressions for themselves in the rubber instead of cutting into the metal shaft. The particles eventually work their way through the bearing without causing shaft wear or damage and without harming the rubber. When an unyielding nonrubber bearing is used under similar conditions, sand or other abrasive particles are not able to make room for themselves and therefore actually become tiny cutting tools which tend to embed themselves in both shaft and bearing, thus causing rapid wear.

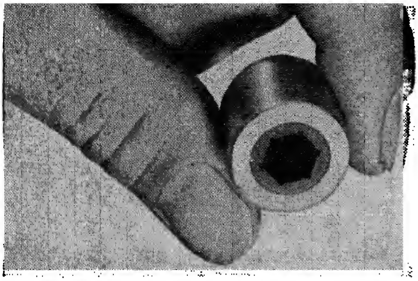


Fig. 4. This cutless rubber bearing, one of the smallest ever made for commercial use, was designed for a machine that dispenses soft drinks. The shell is bronze.

Construction. 1. *Full-molded Type.* The outer shell is a metal cylinder, with or without flanges, to which the bearing surface of soft, tough rubber is vulcanized. Running lengthwise of the bearing are parallel water grooves. The faces between them are carefully designed as to size and contour, so the shaft will be carried on a water film supported by the faces. The water grooves, besides carrying lubricant to the faces, carry away sand and other grit that work into the bearing.

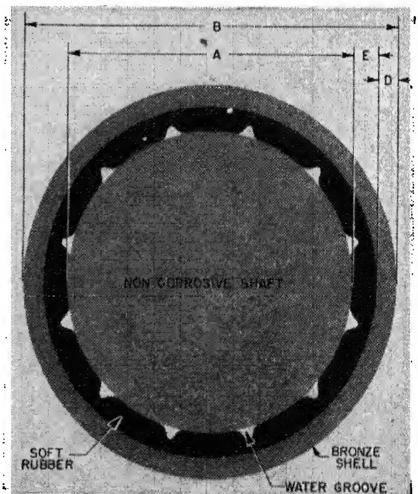


Fig. 5. Cross section of a full-molded type of rubber bearing. *A*, shaft diameter. *B*, outside diameter. *D*, metal-wall thickness. *E*, rubber-wall thickness.

Rubber Hardness. This is about the same as that of a typical automobile tire tread.

Bearing-shell Material. Cast iron, steel, bronze, Monel metal, or other materials are available.

Design. This type may be solid or split, flanged or plain, or specially shaped to customer's needs.

Cutless rubber bearings made of Ameripol D are available for service wherever oil is likely to come into contact with the bearing lining.

2. *Segmented Marine Type.* This bearing provides the same soft rubber bearing surface as the full-molded type but has the added feature of removable segments. This makes it a simple matter to renew one or more damaged segments or to replace all of them, usually without removal of the bearing. Each segment is a rubber strip vulcanized to a

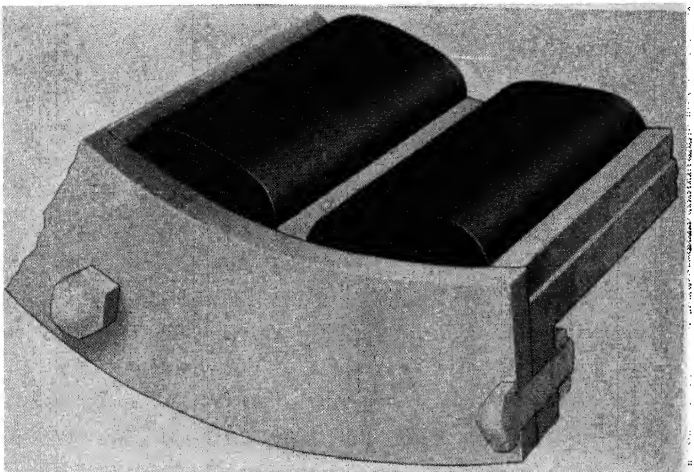


FIG. 6. Section of a segmented-type rubber bearing showing flanged end secured with bolts.

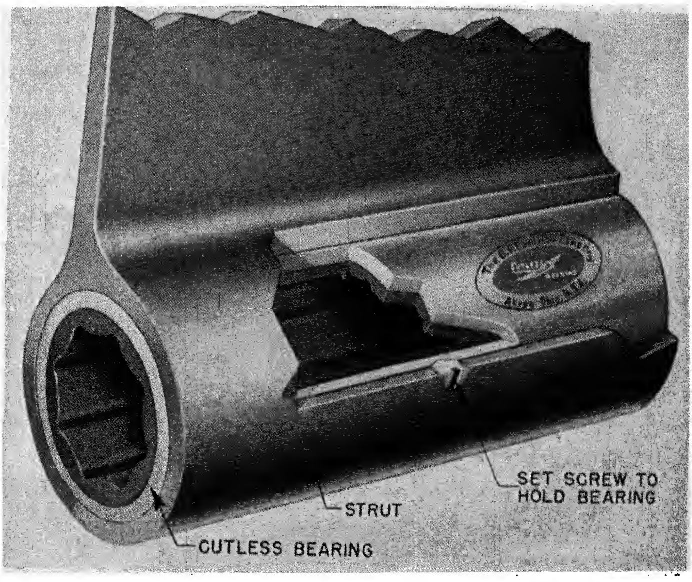


FIG. 7. Sectional view of a standard cutless rubber bearing installed in a strut. Set screws do not extend through the rubber lining.

metal base that fits into dovetail grooves in the bearing shell and is held by a bolted retaining ring or other locking arrangement. Each segment constitutes a bearing face.

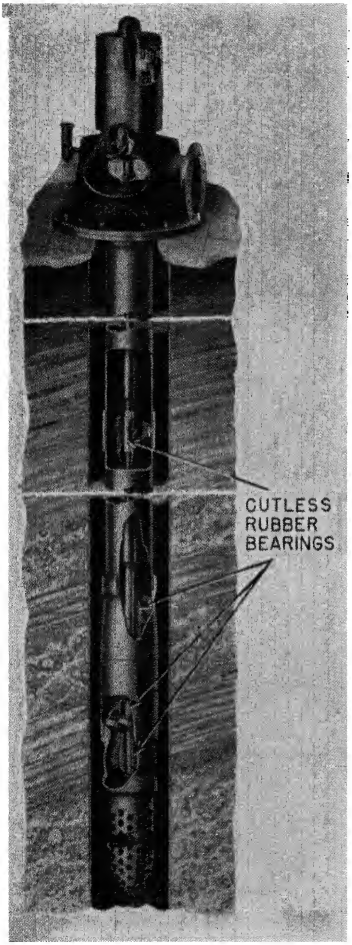


FIG. 8. Cutless rubber bearings are standard equipment in many deep-well pumps and are used both on the upper line shaft and in the bowls, as shown.

3. *"All-rubber" Type.* This bearing is simply a rubber sleeve that has no outer metal shell but fits in a suitable housing designed to hold it in place. "Allrubber" bearings are particularly designed for use on vertical shafts of small and medium sizes such as those encountered in deep-well pumps and some types of agitators.

TYPICAL INDUSTRIAL APPLICATIONS. *Vertical Turbine Pumps.* Rubber underwater bearings have eliminated a formidable problem. Other types of bearings requiring lubrication with oil may be damaged continuously by sand, may permit excessive vibration, or may contaminate the water with oil. Cutless bearings have given years of service on all sizes of this type of pump. They can be run with loose shaft fits without being damaged by pounding and are practically unaffected by sand, and their low coefficient of friction reduces power loss.

Hydraulic Turbines. Rubber bearings used on hydraulic power-generating turbines have given more than 10 years of service without replacement. There are now in use rubber-bearing-equipped turbines developing over 1,000,000 horsepower.

Horizontal Centrifugal Pumps. Lubrication is simplified and shaft and bearing wear reduced on all sizes of horizontal pumps, such as sand and gravel dredge pumps and drainage pumps.

Other industrial applications include foot and steady bearings in agitators; bearings in mixers and strainers, in coal washers, air washers (air conditioners), and other washing machinery; and idler pulley bearings on underwater conveyors.

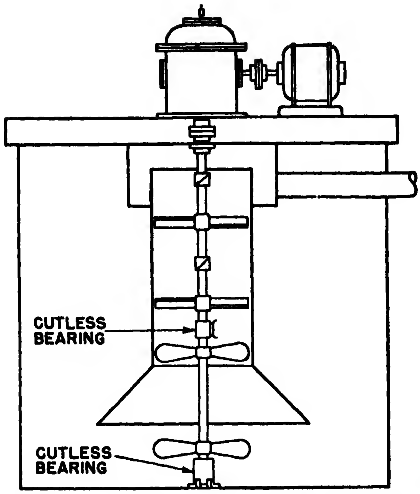


FIG. 9. Cutless rubber bearings applied to a common type of agitator and lubricated by whatever liquid is handled.

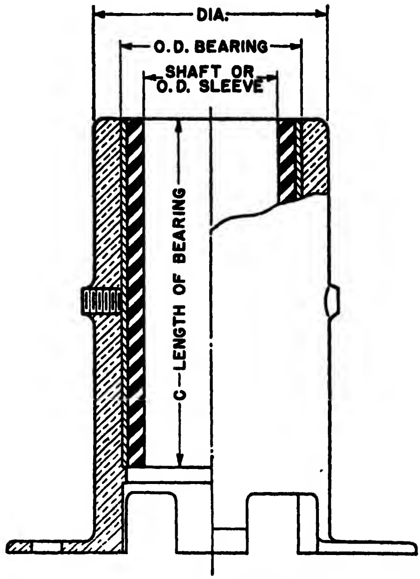


FIG. 10. Rubber-lined foot bearing used in agitator shown in Fig. 9.

INSTALLATION NOTES

The following suggestions pertain primarily to marine-type rubber bearings but can be applied equally well to many industrial installations:

SHAFT MATERIAL. Bronze, stainless steel, and Monel metal are recommended. Ordinary cold-rolled and some alloy steels can be used occasionally, but usually one of the nonrusting metals is preferred. Stainless- and ordinary steel shafts may be chromium-plated to increase surface hardness. Cold-rolled and similar steel shafts may be fitted with sleeves of bronze or other rust-resisting metal. This construction is used in marine installations.

SHAFT HARDNESS. The shaft should be made of tough metal sufficiently hard to resist wear. A soft shaft is subject to cutting and scoring, and any roughness thus caused is detrimental to the bearing.

SHAFT STIFFNESS AND STRAIGHTNESS. The shaft should be sufficiently stiff to prevent excessive whipping and should be straight. In a boat, a whipping shaft may absorb as much as 10 per cent of the engine power, besides imposing strain on the bearing. A shaft that is out of true will not pound in a rubber bearing as it would in a metal one, but it causes uneven bearing wear, particularly at the ends.

SHAFT FINISH. The portion of a shaft in contact with a rubber bearing should be true in size and roundness and absolutely smooth. Surface irregularities wear down much less rapidly than they would in a solid metal bearing and thus are likely to cause excessive wear of the bearing rubber. Shafts to be used in rubber bearings should be ordered "ground and polished" or with a "piston finish." Such smoothness will cause the rubber bearing surfaces to take on a high polish that resists wear and reduces friction.

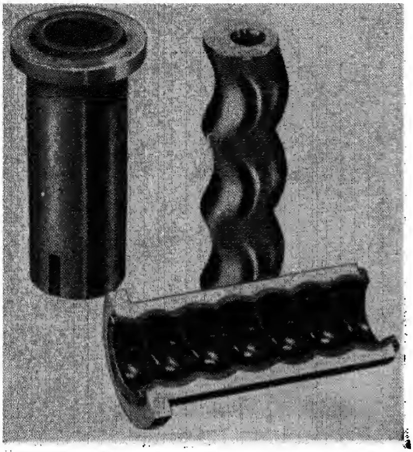


FIG. 11. An adaptation of the rubber-bearing principle is seen in this rubber-lined part for a Moyno pump as manufactured by Robbins and Myers, Inc., Springfield, Ohio. Such pumps are used widely on many types of installations from household water systems to difficult industrial applications. The spiral rotor revolving in the spiral-shaped, rubber-lined brass cylinder will pump practically anything that will flow—from molasses and potato salad to very thin fluids like liquid propane or liquid CO_2.

BEARING INSTALLATIONS. Ease and simplicity of installation are features of rubber bearings. The bearing shells are finished to accurate dimensions as a means of ensuring ease of replacement, and housings to receive them should be machined to matching sizes. The bearing should slide into the housing with a light press fit. If driving is required to force it into place, the shell can be dressed down with abrasive cloth or by any other suit-

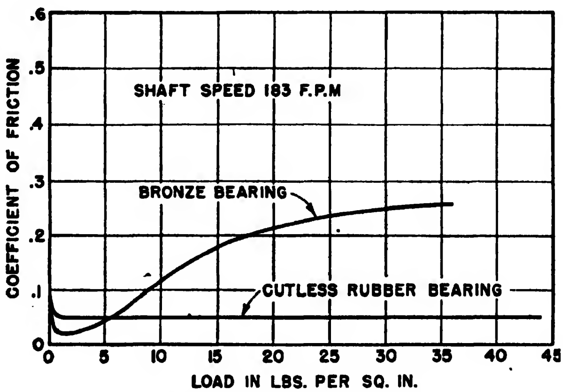


FIG. 12. Comparison of coefficient of friction of water-lubricated metal and rubber bearings at a constant shaft speed and varying loads.

able means until it can be pressed into position with a block of wood placed over its end.

In about 99 per cent of industrial applications and in many marine installations, the bearing can be locked in place by two or more bronze, Monel metal, or stainless-steel setscrews. The bearing housing should be drilled and tapped for the setscrews before the bearing is inserted. Then with a drill bit, a recess for the end of each setscrew is spotted in the bearing shell; this should go about halfway through the shell, but never far enough to enter the rubber. Lock nuts or screws can be used to prevent setscrews from loosening, or the setscrews themselves may be of a self-locking type. In some instances, screws having serrated ends that bite into the bearing shell might be used, without drilling recesses in the shell. Roughness created by the serrations might influence bearing removal.

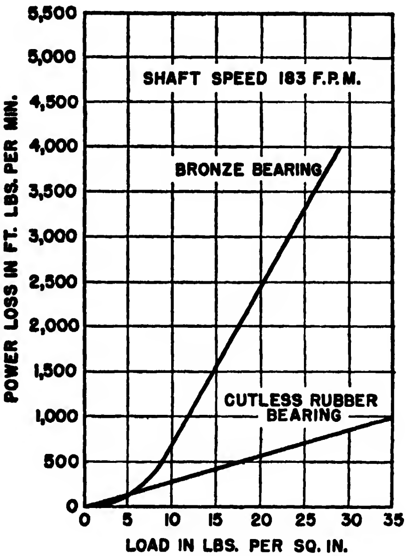


FIG. 13. Comparison of power losses in water-lubricated metal bearings and rubber bearings at constant shaft speed and varying loads.

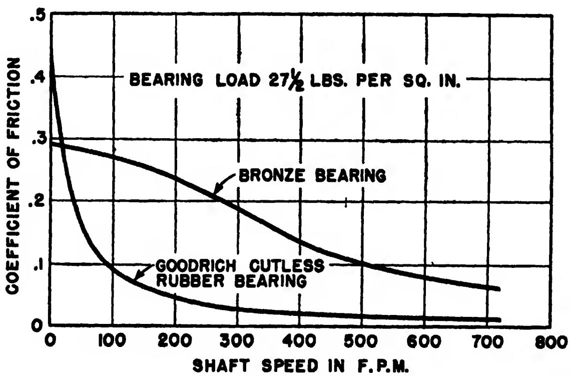


FIG. 14. Comparison of coefficients of friction of bronze bearings and rubber bearings with constant load and varying shaft speed.

CLEARANCES. Proper running clearance is provided in each rubber bearing at the factory. To maintain this, shafts of specified diameter should always be used. The shaft diameter generally is marked on the

bearing. The shaft should slide in the bearing with an easy running fit and should turn readily by hand when the rubber is wet. Bearings should, of course, be in proper alignment, although rubber bearings will tolerate greater misalignment than similar metal types. Oil or grease never should be applied to a rubber bearing to facilitate installation of the shaft. Use water if lubricating is required; or for large, heavy shafts, a special, temporary lubricant called "Rub Lube" can be provided.

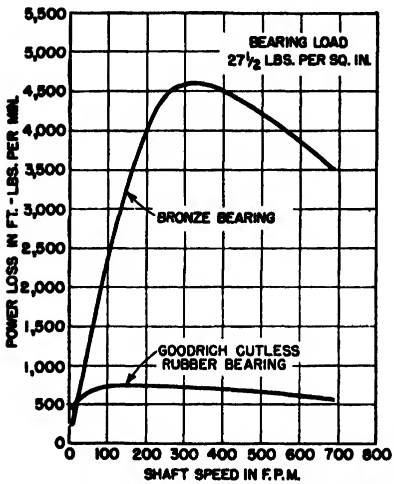


FIG. 15. Comparison of power losses in metal and cutless rubber marine bearings.

STORAGE. The rubber compound used in cutless rubber bearings will retain its resiliency and strength for years. This is true of spare bearings when they are stored where strong sunlight and heat do not reach them.

PERMAPROOF

Permaproof compounds were developed for treating textile fabrics to impart three important properties:

1. FLAMEPROOFING. Treated fabric is not absolutely fireproof in the sense that asbestos is fireproof, but it will burn only while an external flame is applied to it. As soon as the flame is removed, gases developed

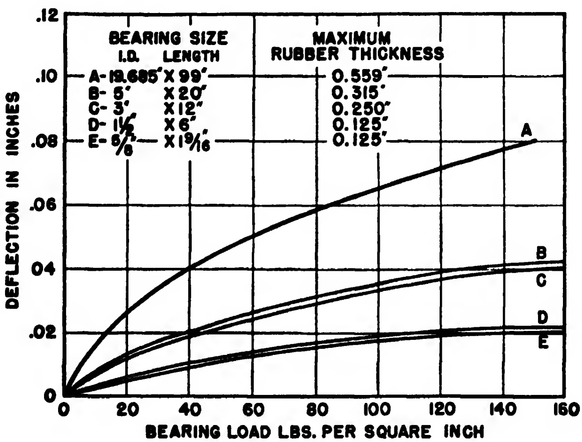


FIG. 16. Load-deflection curves for different-sized rubber marine bearings.

by decomposition of the Permaproof ingredients smother any flame that attempts to continue in the treated fabric.

2. WATERPROOFING. Permaproof renders tarpaulins, tents, and other fabric products resistant to water penetration. In extremely adverse conditions, slight seepage might occur, just as most so-called "waterproofing" compounds show permissible leakage under severe tests.

3. MILDEWPROOFING. Fabric treated with Permaproof is resistant to the attacks of various fungus growths in hot, humid climates. In soil-burial and other accelerated mildew tests, such fabric loses only a small percentage of its tensile strength.

Permaproof compounds are sold as liquid preparations, some of which require diluting before application. The Permaproof 100 series is designed for treating tents, tarpaulins, awnings, hatch covers, etc. These compounds contain about 85 per cent solids. The user dilutes them to desired consistency with lead-free gasoline or similar solvent.

APPLICATION. Permaproof is applied to cloth preferably by dipping followed by squeezing and drying at a temperature of 100 to 120°C (212 to 248°F). Application by brushing, followed by drying at room temperature, gives good results, but fabric colors are likely to be masked to a greater degree. For brushing, solid content is 40 to 50 per cent.

COLOR. Translucent Permaproof compound, when applied by dipping and drying at elevated temperatures, masks the fabric colors only slightly. Permaproof can be colored to match the fabric color.

Covering power depends on type of fabric, concentration of compound, and dry add-on and wet pickup desired; *e.g.*, ordinary 10-ounce flat duck would require about 1 gallon of brush-applied Permaproof 105-45 for every 15 square yards.

Permaproof will withstand repeated washings and prolonged weathering. It does not tenderize fabric, but actually increases the strength at least 10 per cent. Permaproof 200 series, designed primarily for interior use (on curtains, drapes, upholstery, etc.), has all the features of the 100 series, plus the ability to withstand dry cleaning. It is applied in aqueous form, which, from a processing standpoint, is desirable because the solution is noninflammable.

Permaproof can be formulated to meet specific requirements by varying the relative resistance to water, mildew, and flame.

It has been found that the best procedure for the prospective user of this preparation to follow is to submit fabric samples of 1 to 2 square yards to the manufacturer (B. F. Goodrich Company) for processing. This generally gives quicker and more reliable results than when samples of Permaproof are supplied to the fabric processer.

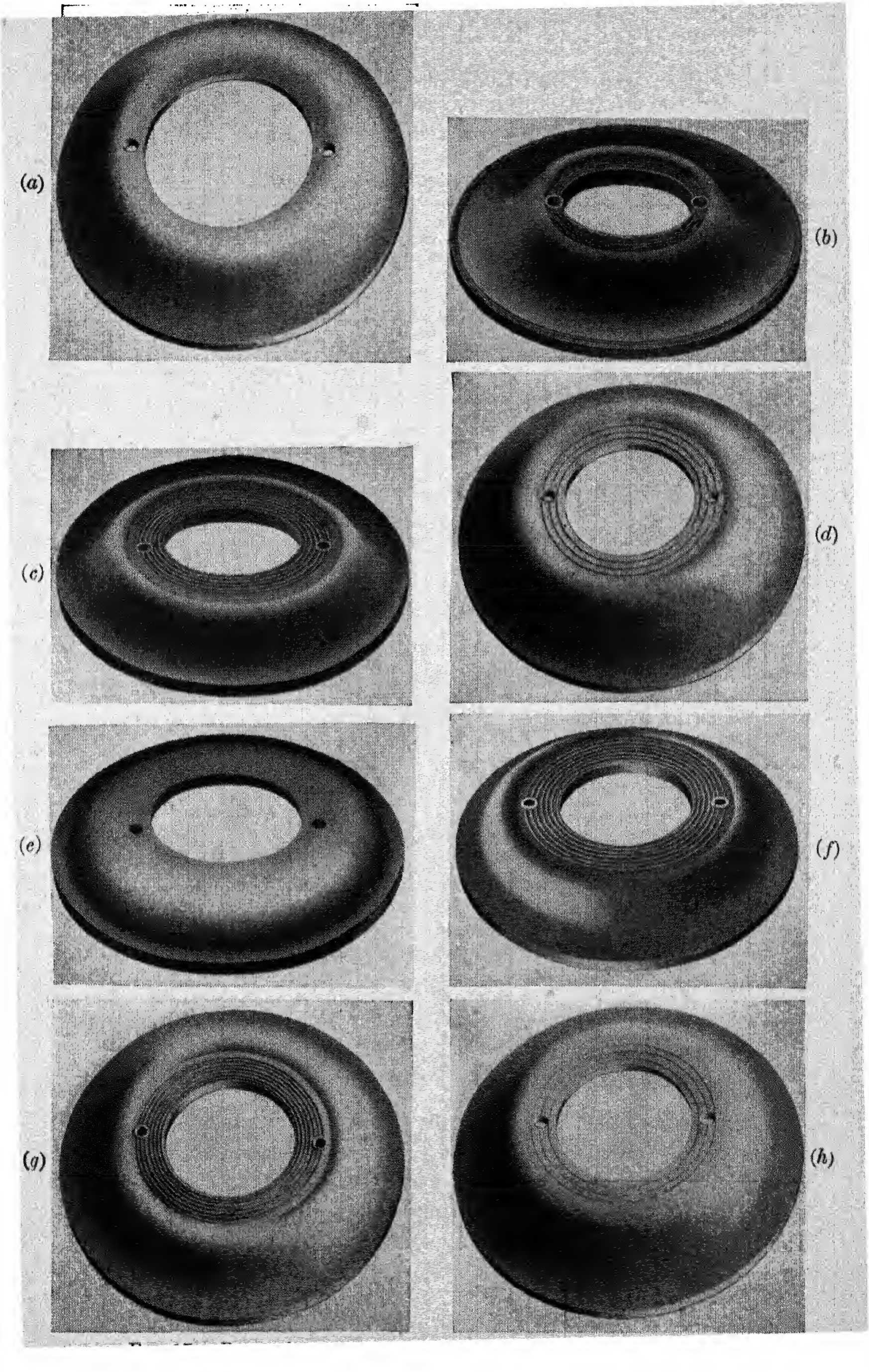
Pump Valves

Rubber is superior to other materials for valves in piston- and plunger-type pumps because of its resilience, which makes possible better contact with the valve seat and consequently more effective checking of backward flow. Such valves are merely disks having central holes through which the valve stem passes. Valves are compounded to meet various service requirements. Very soft rubber is preferable for cold-water pumping at pressures under 50 pounds; harder compounds are used for higher temperatures and pressures. Table 2 shows typical characteristics and service recommendations for rubber pump valves.

Table 2. Pump-valve Data

Service	*Grade characteristics*	*Max. water pressure, lb*		*Max. temp. °F*	*Specific gravity*	*Wt. lb/in.³*
		Cold	*Warm*			
Boiler feed pumps Vacuum pumps on return lines from heating systems General hot-water service	Bone hard, black	.	250	212	1.72	0.063
Mine pumps with high lift Surface condensers General service with cold or warm water	Semihard, gray	250	150	170	1.67	0.060
Water works pumps Gritty liquids, brine Beverages, syrup Dilute acids General cold-water service	Semisoft, gray	150	100	150	1.74	0.063
Marine jet condenser air pumps Pulsometers Slip or sand pumps General low-pressure service with cold or warm water	Very soft, tough, blue	50	50	170	1.86	0.067
To meet underwriters' specifications........	Semihard, gray	250	150	170	1.67	0.060

Hydraulic elevator pumps—A valve as soft as the pressure will permit should be selected, because hard, stiff valves are noisy in operation.
For special grades, consult manufacturer.


(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)

Pump Diaphragms

These are molded ring-shaped disks of rubber reinforced with cotton fabric, for use in trench pumps. Table 3 indicates the interchangeability of diaphragms among several makes of pumps.

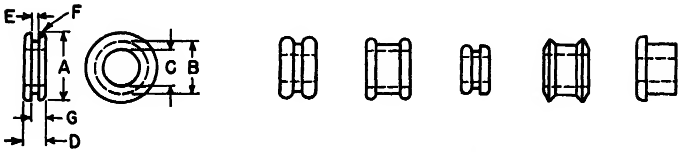
TABLE 3. PUMP-DIAPHRAGM DATA

Pump make and diaphragm No.	*Over-all diam., in.*	*Height, in.*	*Diam., center to center of holes, in.*	*Weight, lb/100 pieces*
No. 1 Loud, No. 1 Deming, No. 1 Douglas, No. 2 Barnes	9¾	1 17/32	5 3/8	75
No. 2 Loud, No. 2 Deming, No. 2 Douglas, No. 3 Barnes	13	1 9/32	6 ¾	152
No. 2 Edson, No. 2 Rumsey	11⅛	1 13/32	4 5/8	89
No. 2 Gould	11	1 13/16	4 ¾	103
No. 3 Edson, No. 3 Rumsey, No. 3 Douglas	12 7/8	1 17/32	6 11/16	151
No. 3 Gould, No. 3 Domestic, No. 3 Nelson	12¾	1 7/8	6 ¾	150
No. 4 Edson, No. 4 Rumsey, No. 4 Douglas	14¾	2 1/16	6 15/16	257
No. 4 Gould, No. 4 Domestic, No. 4 Nelson	14½	2 33/64	7	253

FIG. 17. Rubber pump diaphragms. Names given for each type are those of the pumps in which it is used (see Table 3). (*a*) No. 1 Loud, No. 1 Deming, No. 2 Barnes, No. 1 Douglas. (*b*) No. 2 Edson, No. 2 Rumsey. (*c*) No. 3 Edson, No. 3 Rumsey, No. 3 Douglas. (*d*) No. 4 Edson, No. 4 Rumsey, No. 4 Douglas. (*e*) No. 2 Loud, No. 2 Deming, No. 3 Barnes, No. 2 Douglas. (*f*) No. 2 Gould. (*g*) No. 3 Gould, No. 3 Domestic, No. 3 Nelson. (*h*) No. 4 Gould, No. 4 Domestic, No. 4 Nelson.

Bushings and Grommets

Made of slow-aging, tough, usually black rubber compound, bushings and grommets are used extensively for preventing wires, rods, tubes, and other parts from coming into contact with holes in sheet metal and other materials. Typical shapes and sizes are shown in Fig. 18 and Table 4.



1 2 3 4 5 6

FIG. 18. Various forms of rubber grommets (see Table 4).

TABLE 4. RUBBER GROMMETS

Type	*Sizes, in.*							*Wt., lb/M*
	A	*B*	*C*	*D*	*E*	*F*	*G*	
6	5/8	7/16	1/4	17/32	...	...	5/32	3 3
4	5/8	1/2	1/4	7/16	3/16	1/16	...	10 7
3	3/4	9/16	3/8	3/4	3/8	3/32	...	7 5
2	21/32	15/32	9/32	9/16	3/16	3/32	...	4.
5	1 9/16	1 1/4	7/8	3/4	3/16	...	...	31.
2	3/4	9/16	3/8	3/8	1/8	1/16	...	4.3
6	2 3/16 × 1 5/16 Oval	1 5/16	5/16	1/2	...	3/32	5/16	38.5
1	11/16	1/2	3/8	9/32	1/16	7/64	...	2.45
6	1 1/16	3/4	5/16	1/2	...	3/32	5/16	15.
1*	3/4	9/16	3/8	7/32	3/32	...	...	2.7
2	1	3/4	5/16	1/2	5/32	...	..	11.
1†	11/16	1/2	3/8	1/4	1/16	...	..	2 35
2	5/8	7/16	5/16	3/8	1/8	...	...	2 45
1	1 1/16	13/16	33/64	5/16	1/16	3/32	...	9
1	1 1/16	13/16	37/64	5/16	1/16	3/32	...	7 5
1	1 1/8	7/8	41/64	5/16	1/16	3/32	...	8.1
1	1 5/16	1	45/64	3/8	1/16	1/8	..	15.
1	7/8	5/8	25/64	5/16	1/16	3/32	.	6.
1	7/16	5/16	1/8	3/16	1/16	3/64	...	1 95
1	7/16	5/16	13/64	3/16	1/16	3/64	..	1.6
1	1 3/8	1 1/16	49/64	3/8	1/16	1/8	. .	12.5
1	5/8	7/16	17/64	3/16	1/16	3/64	..	1 8
1	15/16	11/16	29/64	5/16	1/16	3/32	...	6 4
1	13/16	9/16	21/64	5/16	1/16	3/32	...	5 7
1	1 5/8	1 1/4	57/64	7/16	1/16	1/8	..	26 6
1	1 3/4	1 3/8	1 1/32	7/16	1/16	1/8	...	28
1	1 3/4	1 3/8	1 1/8	7/16	1/16	1/8	..	31 25
1	1 1/2	1 1/4	1/2	1/4	1/16	3/32	...	15 5
1	1 1/2	1 1/4	5/8	1/4	1/16	3/32	...	15
1	1 5/8	1 1/4	3/4	1/4	1/16	3/32	...	15 5
1	1 1/4	1	3/8	1/4	1/16	3/32	...	12.5
1	1 1/4	1	1/4	1/4	1/16	3/32	...	13.
1	1 1/4	1	1/8	1/4	1/16	3/32	...	14.
1	3/4	9/16	3/16	3/16	1/16	1/16	...	3.4
1	1	3/4	5/16	5/16	1/16	3/32	...	9.6
1	1 13/16	1 7/16	3/4	3/8	1/16	1/8	...	31.
1	2	1 5/8	7/8	7/16	1/16	1/8	...	45.
1	2 1/4	1 7/8	1	7/16	1/16	1/8	...	58.
1	2 3/4	2 3/8	1 1/4	7/16	1/16	1/8	...	86.
1	2 1/8	1 3/4	1 1/2	7/16	1/16	1/8	...	35.

* One flange 1 1/16 inch outside diameter.

† One flange 5/8 inch outside diameter.

Press-die Pads

These are resilient slabs of rubber of either one-piece or laminated construction, used in the die forming of sheet metal.

A Typical Application. A die made by engraving a design in Tempered Masonite Presdwood is placed on the lower platen of a hydraulic press. Over this is laid a sheet of aluminum. The rubber pad is then placed on the aluminum. When the press platens close, the rubber, being an incompressible but distortable material, forces the sheet aluminum down into the die depressions. When a relatively hard die pad is used, it may act in conjunction with the die to trim the formed piece.

Rubber press-die pads are made in various hardnesses, thicknesses, widths, and special shapes. Typical hardness ranges from 35 to 70 durometer; thickness, 1/8 to 12 inches and more; area, up to 4 by 13 1/3 feet. These are merely examples of characteristics and do not indicate ultimate values. In all cases, pads are furnished to customers' specifications. When the customer does not know what characteristics he should specify, he should consult the manufacturer of the press he intends to use. For the process of using rubber press-die pads, technical information may be obtained from Douglas Aircraft Co., Inc., Santa Monica, Calif.

Laboratory Stoppers

Rubber corks, used widely in laboratory work, are normally made 1 inch long. They may be obtained with one or two holes or without holes. The compound is designed to be nonblooming.

Table 5. Laboratory Stoppers

Diameter, in.		Length, in.	Size of holes	Pieces per pound		
Top	Bottom			Solid	1 hole	2 holes
9/16	3/8	1	1/8	128	137	149
5/8	1/2	1	1/8	89	93	98
3/4	9/16	1	5/32	68	73	77
25/32	5/8	1	5/32	62	66	70
29/32	23/32	1	3/16	43	45	48
1	3/4	1	3/16	35	37	39
1 1/8	27/32	15/16	7/32	30	31	33
1 1/4	1	1	7/32	22	22	23
1 3/8	1 3/32	1	7/32	16	17	17
1 5/8	1 9/32	1	7/32	14	14	15
1 3/4	1 7/16	1	7/32	11	12	12
2	1 5/8	1 1/16	7/32	9	9	9
2 3/16	1 15/16	1	1/4	6	6	7
2 9/16	2 1/4	1	1/4	5	5	5
2 11/16	2 5/16	1	1/4	4	4	4

SANDBLAST STENCIL SHEET

Rubber sandblast stencil sheet is made primarily for use in engraving names and other designs on tombstones and monuments. It can be adapted to other purposes such as the decorating of art-glass objects, selective cleaning of metal, and the making of novel signs of wood, stone, metal, etc.

The sheet normally used is 0.015 inch thick, has one tacky surface protected by Holland cloth until used, and is made in rolls measuring approximately 39 inches by 50 yards. Other thicknesses and roll sizes are available.

USE. Wherever the lettering or other design is to be cut into the monument surface, the rubber sheet is cut away, forming a stencil. By means of the tacky surface, the stencil is attached to the smooth area to be decorated. Sandblast is then directed on the stencil, cutting into the stone wherever it is unprotected by rubber. The depth of cut is regulated by the operator. The rubber compound is of a special type designed to withstand the sandblast and yet permit easy cutting to produce a design having sharp, even edges. The adhesion is sufficient to hold the stencil firmly in place, yet the rubber is easily peeled off after the sandblasting has been completed.

COLD-CABINET LIDS AND COLLARS

COLLARS. Rubber collars are used around the throats of frozen-food and ice-cream cabinets to form a thermal break that prevents frost from

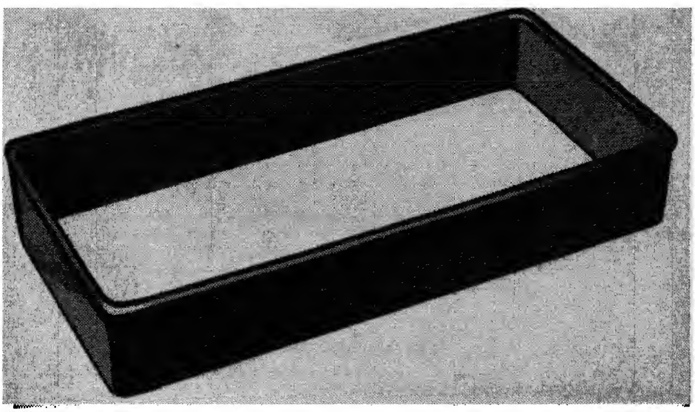


FIG. 19. A cold-cabinet collar that is attached to the cabinet throat by screws passing through a rigid core.

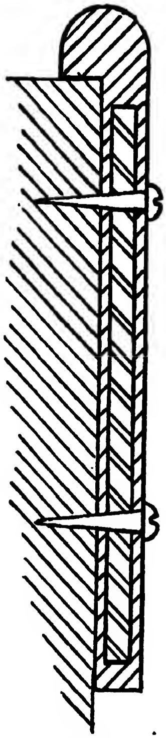


FIG. 20. Method of attaching a cold-cabinet collar that has a rigid core of Masonite Presdwood or similar material.

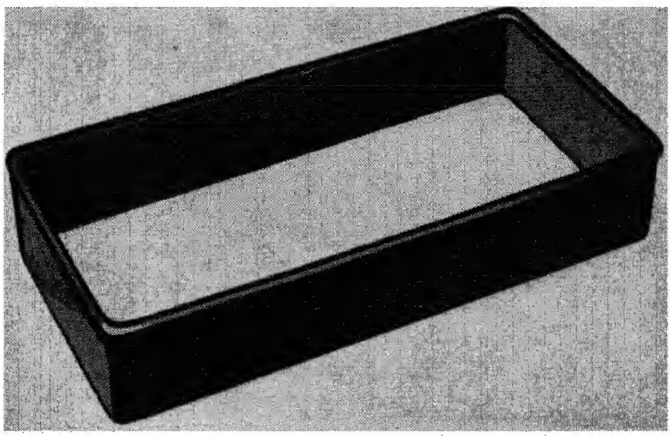


FIG. 21. A cold-cabinet collar that is mounted by slipping it over metal strips attached to cabinet.

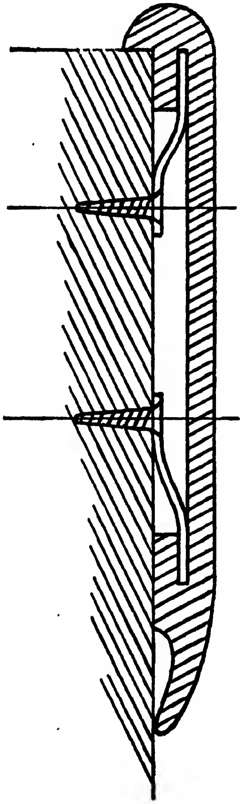


FIG. 22. Cross section of a cold-cabinet collar that is held in position by metal strips.

FIG. 23. Hinged all-rubber cold-cabinet lid of a type used on ice cream, frozen food, and other low-temperature cabinets.

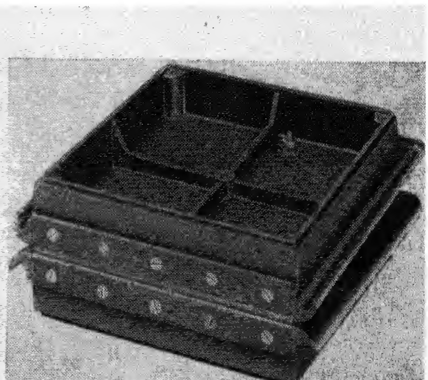


FIG. 24. Rubber cold-cabinet lid in open position showing the one-piece rubber hinge.

accumulating at the opening and causing lids to stick. Rubber, because of its low thermal conductivity, does not "transmit" frost. In a properly designed throat collar installation, frost may form over the lower edge of the collar but will not continue to the top. Such collars are designed to fit each particular cabinet. The rubber is compounded to resist moisture, fats, milk products, sirups, and processing solutions and to remain unaffected at high and low temperatures. The color normally used is black. Collars are fastened in various ways: by means of stainless-steel strips and screws, screws passing through embedded Masonite strips, metal angle strips over which lips on the collar hook, etc. The upper collar edge may be designed to form a hollow gasket seal.

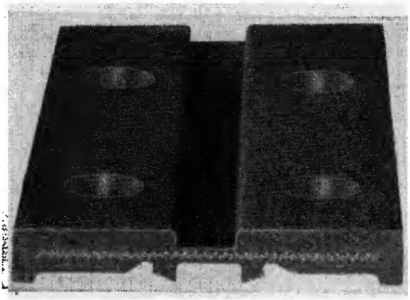


FIG. 25. Rubber cold-cabinet-lid hinge cut to show cross-sectional construction involving a fabric reinforcement.

LIDS. Rubber cold-cabinet lids will withstand more abuse than those made of metal or other material. A typical lid compound has a rigidity approaching that of hard rubber, yet is soft enough to be resilient and shockproof. The edges of the lid form a tight seal against the cabinet throat collar.

The lids usually are mounted in pairs and are connected by a hinge. Metal piano-type hinges have been used. B. F. Goodrich engineers developed a nonmetal hinge consisting of flexible rubber reinforced by fabric. It requires no lubrication, cannot corrode, cannot be sprung by severe handling, and will not let spilled liquids leak back into the cabinet. In an "open-and-shut" test, such a hinge withstood 750,000 flexures under accelerated aging conditions without showing appreciable strength change. The test represented five years of normal service.

Cabinet lids are normally black and withstand the same liquids, etc., as throat collars.

HELPFUL INFORMATION

In the calculating of weights and dimensions of rubber products, the following may be helpful:

HOW TO ESTIMATE WEIGHTS

Specific gravity × 0.0361 = pounds per cubic inch

Weight of articles of plain rectangular shape = length × width × thickness (all in inches) × weight per cubic inch.

Volume of plain rings, tubes, disks, or cylinders of rectangular cross section[1] is computed by using Table 7 of areas of circles. Find area of circle corresponding to outside diameter. Subtract from this the area corresponding to the inside diameter and multiply the net area by the length of the tube or the thickness of the ring as the case may be.

Example:

To find the approximate weight of a valve—specific gravity 1.77 – 6 inch diameter by 7/8 inch thick by 13/16-inch hole:

Volume = (28.274 – 0.518) × 7/8 = 24.287 cu in.

Weight per cu in. = 1.77 × 0.0361 = 0.0639 lb

Approximate weight = 24.287 × 0.0639 = 1.56 lb

If it is desired to find the area of a circle larger than 12 inches, take the area of a circle with one-half the diameter and multiply by 4. For example, the area of a circle 14½ inches in diameter is four times the area of a circle 7¼ inches in diameter.

If it is desired to find the area corresponding to a diameter with a fraction not shown on the table, take the area corresponding to just twice the diameter and divide by four. For example, the area of a circle 4 3/16 inches in diameter is one-fourth the area of a circle 8⅜ inches in diameter.

Important: Estimated weights should be considered only as approximate. Slight variations are always likely to occur in dimensions and in specific gravities of compounds.

TABLE 6. FRACTIONS INTO DECIMALS

In.	*16ths*	*32nds*	*64ths*	*Decimals*
			1	0.015625
		1	2	0.03125
			3	0.046875
	1	2	4	0.0625
			5	0.078125
		3	6	0.09375
			7	0.109375
⅛	2	4	8	0.125
			9	0.140625
		5	10	0.15625
			11	0.171875
	3	6	12	0.1875
			13	0.203125
		7	14	0.21875
			15	0.234375
¼	4	8	16	0.250
			17	0.265625
		9	18	0.28125
			19	0.296875

[1] "Rectangular cross section" refers to section obtained by cutting tube or ring wall in a radial plane.

TABLE 6. FRACTIONS INTO DECIMALS.—(*Continued*)

In.	*16ths*	*32nds*	*64ths*	*Decimals*
	5	10	20	0.3125
			21	0.328125
		11	22	0.34375
			23	0.359375
3/8	6	12	24	0.375
			25	0.390625
		13	26	0.40625
			27	0.421875
	7	14	28	0.4375
			29	0.453125
		15	30	0.46875
			31	0.484375
1/2	8	16	32	0.500
			33	0 515625
		17	34	0.53125
			35	0.546875
	9	18	36	0.5625
			37	0 578125
		19	38	0.59375
			39	0.609375
5/8	10	20	40	0.625
			41	0.640625
		21	42	0 65625
			43	0.671815
	11	22	44	0 6875
			45	0.703125
		23	46	0.71875
			47	0.734375
3/4	12	24	48	0.750
			49	0.765625
		25	50	0.78125
			51	0.796875
	13	26	52	0.8125
			53	0.828125
		27	54	0 84375
			55	0.859375
7/8	14	28	56	0.875
			57	0.890625
		29	58	0.90625
			59	0.921875
	15	30	60	0.9375
			61	0.953125
		31	62	0.96875
			63	0.984375
1	16	32	64	1.0000

TABLE 7. AREA OF CIRCLES

Diameter	*Area*	*Diameter*	*Area*	*Diameter*	*Area*
1/8	0.012	1 3/32	0.931	4 3/4	17.721
9/64	0.016	1 1/8	0.994	4 7/8	18.666
5/32	0.019	1 5/32	1.050	5	19.635
11/64	0.023	1 3/16	1.108	5 1/8	20 629
3/16	0.028	1 7/32	1.167	5 1/4	21.648
13/64	0.032	1 1/4	1.227	5 3/8	22.691
7/32	0.038	1 9/32	1.289	5 1/2	23.758
15/64	0.043	1 5/16	1.353	5 5/8	24.851
1/4	0.049	1 11/32	1.418	5 3/4	25.967
17/64	0.055	1 3/8	1.485	5 7/8	27 109
9/32	0.062	1 13/32	1.553	6	28.274
19/64	0.069	1 7/16	1.623	6 1/8	29.465
5/16	0.077	1 15/32	1.694	6 1/4	30.680
21/64	0.085	1 1/2	1.767	6 3/8	31.919
11/32	0 093	1 17/32	1.842	6 1/2	33 183
23/64	0.101	1 9/16	1.917	6 5/8	34.472
3/8	0.110	1 19/32	1.995	6 3/4	35 785
25/64	0.120	1 5/8	2.074	6 7/8	37.122
13/32	0.130	1 21/32	2.154	7	38 485
27/64	0.140	1 11/16	2.237	7 1/8	39.871
7/16	0.150	1 23/32	2.320	7 1/4	41.283
29/64	0.161	1 3/4	2.405	7 3/8	42.718
15/32	0.173	1 25/32	2.492	7 1/2	44 179
31/64	0.184	1 13/16	2.580	7 5/8	45 664
1/2	0.196	1 27/32	2.670	7 3/4	47.173
33/64	0.209	1 7/8	2.761	7 7/8	48 707
17/32	0.222	1 29/32	2.854	8	50 266
35/64	0 235	1 15/16	2.948	8 1/8	51 849
9/16	0.249	1 31/32	3.044	8 1/4	53 456
37/64	0.263	2	3.142	8 3/8	55 088
19/32	0.277	2 1/16	3.341	8 1/2	56.745
39/64	0 292	2 1/8	3.547	8 5/8	58 426
5/8	0 307	2 3/16	3.758	8 3/4	60.132
41/64	0.322	2 1/4	3.976	8 7/8	61.863
21/32	0.338	2 5/16	4.200	9	63 617
43/64	0.355	2 3/8	4.430	9 1/8	65 397
11/16	0.371	2 7/16	4.666	9 1/4	67.201
45/64	0.388	2 1/2	4.909	9 3/8	69.029
23/32	0.406	2 9/16	5.157	9 1/2	70 882
47/64	0.424	2 5/8	5.412	9 5/8	72 760
3/4	0.442	2 11/16	5.673	9 3/4	74 662
49/64	0.460	2 3/4	5.940	9 7/8	76.589
25/32	0 479	2 13/16	6 213	10	78.54
51/64	0.499	2 7/8	6.492	10 1/8	80.516
13/16	0.518	2 15/16	6.777	10 1/4	82.516
53/64	0.539	3	7.069	10 3/8	84.541
27/32	0.559	3 1/8	7.670	10 1/2	86.590
55/64	0.580	3 1/4	8.296	10 5/8	88.664
7/8	0.601	3 3/8	8.946	10 3/4	90.763
57/64	0.623	3 1/2	9.261	10 7/8	92.886
29/32	0.645	3 5/8	10.321	11	95.033
59/64	0.667	3 3/4	11.045	11 1/8	97.206
15/16	0.690	3 7/8	11.793	11 1/4	99.402
61/64	0.713	4	12.566	11 3/8	101.623
31/32	0.737	4 1/8	13.364	11 1/2	103.869
63/64	0.761	4 1/4	14.186	11 5/8	106.139
1	0.785	4 3/8	15.033	11 3/4	108.434
1 1/32	0.835	4 1/2	15.904	11 7/8	110.754
1 1/16	0 887	4 5/8	16.800	12	113.098

Chapter 23

VINYL CHLORIDE POLYMERS

As previously explained in Chap. 2, vinyl chloride can be polymerized alone to produce the material known as polyvinyl chloride and can be polymerized together with other chemicals to produce vinyl chloride copolymers, which are somewhat more soluble than PVC and generally require a little less plasticizer.

These adaptable, man-made materials find a place in a book concerning rubber because, when properly compounded and otherwise processed, they possess a number of rubberlike properties, plus some characteristics superior to those of rubber. The discovery of a way to plasticize polyvinyl chloride was in the nature of an accident that occurred during the course of research on adhesives.

Polyvinyl chloride, which often is abbreviated to "PVC" to save space and lung power, is, in a plasticized form, remarkably like rubber in that it, too, is not a definite material. Because of the infinite ways in which it can be modified by compounding with other ingredients, it is in reality "a thousand different materials." This makes it difficult to set forth specific figures and other data concerning properties. The various physical and chemical characteristics mentioned in this chapter are, in many cases, indicative of the *range* of properties normally attainable. A definite property might refer only to a definite sample of a synthetic plastic. By varying the compound ingredients and the processing, wholly different properties, to fit any particular problem, can be produced. Because of this wide range of available characteristics, the designer who believes that a PVC compound may serve his needs better than any other material will find it desirable to let manufacturers' experienced technicians work out the finer details of his problem.

A group of materials closely related to PVC is made by copolymerizing vinyl chloride with vinylidene chloride. The basic resin of either type, which is in the form of a white powder, is modified by the addition of

1. A plasticizer: A nonvolatile, generally liquid organic chemical that softens hard resin to give it the desired flexibility and make it workable. Proportion of plasticizer runs from about 10 to 50 per cent of total com-

pound weight, and corresponding hardness ranges from fairly rigid to the gel state. Common plasticizers are tricresyl phosphate and dioctyl phthalate. Plasticizer selection is important, for it affects physical, chemical, and electrical properties.

2. A stabilizer: When a vinyl chloride resin is subjected to high temperature, hydrogen chloride gas is liberated in very small quantities. The stabilizer discourages the release of this gas, thus increasing temperature resistance and prolonging useful life of the compound. It also improves electrical properties. Stabilizers include compounds of certain metals, such as lead oxide (litharge), basic lead carbonate, lead titanate, lead silicate,[1] calcium silicate,[1] sodium silicate,[1] and certain organic compounds such as glycerides of unsaturated fatty acids.[1]

The selection of a stabilizer is work for an expert, for the inclusion of traces of certain metallic oxides and salts may prove harmful.

3. Pigments: Materials added to impart desired properties. They may be broken down into (*a*) color-producing ingredients such as cadmium red, and covering and color-base pigments such as basic lead carbonate; (*b*) fillers, such as fine hard clay and chalk; (*c*) softeners or modifiers, which are used occasionally to control processing characteristics; (*d*) lubricants such as mineral or vegetable oil or stearic acid, added to some compounds to improve processing characteristics; and (*e*) extenders which include Neoprene, Nitril, and GR-S rubbers, and chlorinated paraffin, asphalt, and alkyd resins.

Properties of PVC Resins and Compounds

Physical Constants of PVC Plastics. Table 1 shows the range of properties obtainable by compounding, and not the properties of any specific compound.

Aging Resistance of PVC Compounds. Three representative compounds were used in aging tests, with results as shown in Table 2.

Toxicity and Contamination. Chemical inertness is one of the outstanding characteristics of plasticized PVC and for this reason it is used in making nontoxic and noncontaminating containers, packaging materials, and other forms used in the processing of food, medicines, and other products. When a PVC plastic is to be used in connection with food, drink, or medicine, information concerning conditions should be supplied by the purchaser so the manufacturer can select a compound that is most suitable for the purpose and free from toxic or otherwise objectionable ingredients.

[1] B. F. Goodrich patent.

TABLE 1. PVC COMPOUND DATA

Compression set	Varies, but usually is somewhat more pronounced than for rubber compounds
Elongation	From almost no elongation to 500% of original length
Flexing life	Greater than that of rubber at normal temperature. Example: A selected rubber compound under test conditions withstands 300,000 flexures; a corresponding PVC compound withstands 3,600,000 flexures. Lowest temperature at which flexibility can be maintained is around −60°F .
Friction, coefficient of:	
Bone-hard compound:	
Dry	0.13–0.16
Lubricated with oil of viscosity 100 sec Saybolt at 100°F	0.13–0.16
Medium-soft compounds:	
Dry	0.20–0.70
Lubricated	0.16–0.30
Soft compounds:	
Dry	1 20–1.80
Lubricated	0 05–0.10
Hardness, Type A Shore durometer.	60 to 100, for batch stocks at 86°F
Specific gravity, unpigmented compound.	1 20–1.41
Specific heat	0 32–0.51
Specific heat conductivity	$K = 39 \times 10^5$ to 33×10^5 cal/sec/cm²/(°C/cm) or 1.13 to 0.96 Btu/hr/ft²/(°F/in.)
Specific volume, unpigmented compound.	23 0–19.8 in.³/lb
Tearing strength	High; usually comparable to rubber
Tensile strength of batch stocks	2,000–3,000 psi
Tensile strength, increasing	By extending PVC beyond elastic limit, tensile strength can be increased as much as 10 times

TABLE 2. AGING OF PVC COMPOUNDS

Aging status	*Compound No.*	*Durometer hardness*	*Ultimate tensile strength, psi*	*Ultimate elongation, %*
Fresh	1	80	2,350	250
	2	80	2,420	300
	3	82	2,400	225
Geer oven at 70°C, (158°F) 2 months	1	86	2,440	220
	2	89	2,470	280
	3	80	2,330	200
Bierer oxygen bomb 200 psi at 70°C (158°F) for 2 weeks	1	83	2,500	265
	2	93	2,520	140
	3	81	2,210	215

TABLE 3. WATER ABSORPTION, PVC PLASTICIZED WITH DIOCTYL PHTHALATE
Exposure to air at 95 to 100 per cent relative humidity. Figures show per cent gain in weight.

Hr exposure	*22°C (room temp.)*	*33°C*	*40°C*
5	0.025	0.04	0.065
10	0.04	0.06	0.095
15	0.055	0.075	0.011
20	0.062	0.088	0.128
30	0.075	0.011	0.142
40	0.082	0.112	0.155
60	0.10	0.13	0.169
80	0.11	0.14	0.173

Immersed in water

Exposure, hours	*22°C (room temp.)*	*41°C*	*60°C*	*70°C*
4	0.05	0.10	0.27	0.50
8	0.08	0.24	0.51	0.66
12	0.10	0.30	0.60	0.76
16	0.14	0.34	0.65	0.83
20	0.15	0.36	0.69	0.89
24	0.16	0.38	0.73	0.93
28	0.17	0.39	0.76	0.97
32	0.18	0.40	0.78	1.00

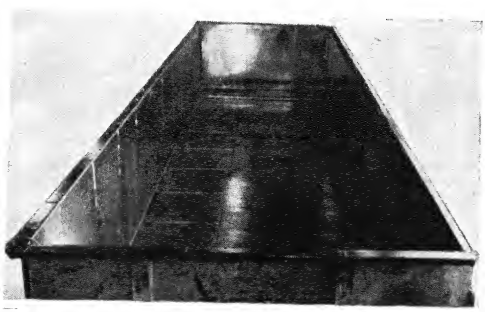
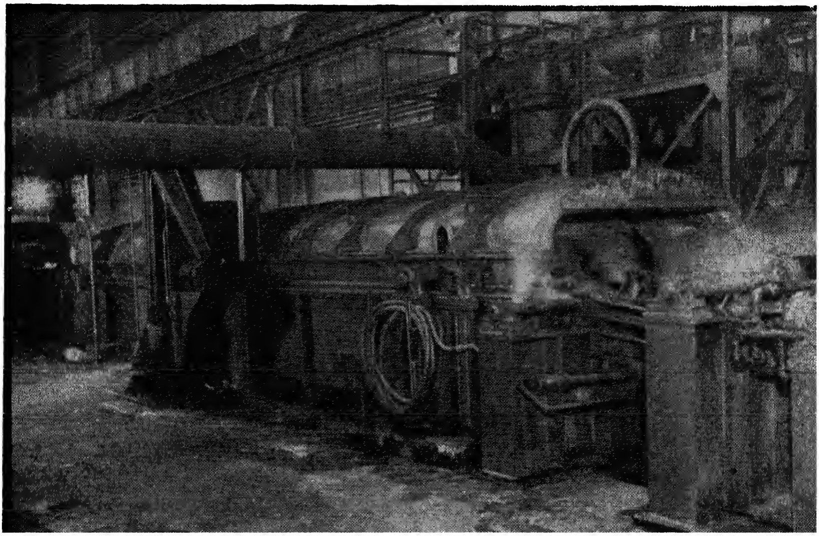


FIG. 1. This steel tank 36 feet long, 9 feet wide, and 4 feet deep has a Koroseal lining and is used in bright nickel plating.

Taste and Odor. Special compounds having virtually no taste or odor are available.

Color. Compounds containing no added pigment vary in color from water white to dark brown, depending upon the degree of stabilization. By adding pigments and dyes, an almost unlimited range of transparent or opaque colors, including brilliant hues and pastel shades, can be produced.

Stability. At normal temperatures, PVC plastics are stable and nonvolatile. Being thermoplastic, they soften as the temperature is in-



and hydrofluoric acid at a temperature of 165°F. The acid is in a steel tank having a Koroseal lining which is insulated from the heat and protected from physical damage by brick sheathing. The tank is similar to that in Fig. 1.

creased. At very high temperatures, compounds decompose. At 150°C (302°F) they remain reasonably stable for 10 hours. Service temperatures are considerably lower, around 150°F maximum.

Sunlight Resistance. Extreme resistance to natural sunlight and to artificial sunlight under accelerated test conditions is an outstanding characteristic. Some compounds have shown no appreciable physical change after 400 hours of exposure to powerful twin-arc lamps.

Oxidation Resistance. This is extremely high. Compounds have shown no appreciable deterioration during several years of exposure to oxygen and ozone in high concentrations. Similar high resistance is shown to chromic, nitric, and other highly oxidizing acids.

Flame Resistance. Some compounds will burn quite readily, some will barely support a flame, and others will not burn except when held

TABLE 4. CHEMICAL RESISTANCE OF PVC COMPOUNDS

Solutions of inorganic acids

	Max. concentration by weight	*Max. temp., °F**
Arsenic	Any	150
Carbonic	Saturation at atmospheric pressure	90
Chlorine water (hypochlorous acid)	Saturation at atmospheric pressure	90
Fluoboric	Any	150
Hydrofluoric	60%	70
Hydrofluoric	4%	150
Hydrogen sulfide in water	Saturation at atmospheric pressure	90
Muriatic (hydrochloric)†	Any	90
Muriatic (hydrochloric)†	22%	140
Nitric	10%	150
Nitric	20%	120
Nitric	35%	90
Phosphoric†	75%	150
Sulfuric	50%	130
Sulfurous (sulfur dioxide in water)	Saturation at atmospheric pressure	90
Chromic acid	25%	130
Hydrogen peroxide†	30%	90
Mixtures of acids:		
Nitric	15%	140
Hydrofluoric	4%	
Sodium dichromate	13%	90
Nitric acid	16%	
Water	71%	

Solutions of inorganic salts and alkalies

Aluminum chloride	Up to saturation	150
Aluminum sulfate	Up to saturation	150
Alums	Up to saturation	150
Ammonium chloride	Up to saturation	150
Ammonium hydroxide	Up to saturation	90
Ammonium sulfate	Up to saturation	150
Barium sulfide	Up to saturation	150
"Black liquor" NaOH, Na_2S, Na_2CO_3	Up to saturation	90
Calcium bisulfite	Up to saturation	150
Calcium chloride	Up to saturation	150
Calcium hypochlorite	Up to saturation	90
Caustic soda (sodium hydroxide)	35%	90
Caustic soda (sodium hydroxide)	10%	150
Caustic potash (potassium hydroxide)	35%	90
Caustic potash (potassium hydroxide)	10%	150

TABLE 4. CHEMICAL RESISTANCE OF PVC COMPOUNDS.—(*Continued*)

Solutions of inorganic salts and alkalies—(*Continued*)

	Max. concentration by weight	*Max. temp., °F**
Copper chloride (cupric)	Up to saturation	150
Copper cyanide (in solution with alkali cyanides)	Up to saturation	150
Copper sulfate (cupric)	Up to saturation	150
Disodium phosphate	Up to saturation	150
Ferric chloride	Up to saturation	150
Ferrous sulfate (copperas)	Up to saturation	150
Nickel acetate	Up to saturation	150
Plating solutions		
Brass, Cadmium, Copper, Gold, Indium, Lead, Nickel, Rhodium, Silver, Tin, Zinc	....	150
Chrome plating	....	130
Potassium cuprocyanide	Up to saturation	150
Potassium dichromate	Up to saturation	150
Sodium or potassium antimonate	Up to saturation	150
Sodium or potassium bisulfite	Up to saturation	90
Sodium or potassium acid sulfate	Up to saturation	150
Sodium or potassium chloride	Up to saturation	150
Sodium or potassium cyanide	Up to saturation	150
Sodium or potassium hypochlorite	Up to saturation	90
Sodium or potassium sulfide	Up to saturation	150
Sodium or potassium thiosulfate	Up to saturation	150
Tin chloride—either stannous or stannic	Any aqueous solution	150
Trisodium phosphate	Up to saturation	150
White liquor ($NaOH$, Na_2S, Na_2CO_3)	....	90
Zinc sulfate	Up to saturation	150
Organic materials		
Amyl alcohol	Any	90
Butyl alcohol	Any	90
Casein	Any	90
Castor oil	....	90
Citric acid	Up to saturation	150

TABLE 4. CHEMICAL RESISTANCE OF PVC COMPOUNDS.—(*Continued*)
Organic materials—(*Continued*)

	Max. concentration by weight	*Max. temp., °F**
Cottonseed oil	....	90
Cocoanut oil	....	90
Ethyl alcohol	Any	90
Ethylene Glycol	Any	90
Food products such as buttermilk, milk, molasses, salad oils, fruit juices, etc‡	....	90
Gallic acid	Up to saturation	150
Glucose	Any	150
Glue	Any	150
Glycerin	Any	90
Hydroquinone	Any	90
Lactic acid	Any	90
Malic acid	Any	90
Methyl alcohol	Any	90
Mineral oils	Any	90
Oleic acid	Any	90
Oxalic acid	Any	90
Propyl alcohol	Any	90
Soaps	Any	150
Tannic acid	Up to saturation	90
Tartaric acid	Up to saturation	90
Triethanolamine	Any	150

* See effect of temperature in paragraph on Stability (page 432).

† Discoloration: Where discoloration is a factor, inquiries should so state as special compounds are required.

‡ Contamination and toxicity: Because of its inert character, PVC is valuable in its freedom from contaminating effect in the processing of food products or other materials in which a high degree of purity is essential. However, special compounds are required and the conditions should be specified by the buyers so that the proper compound may be selected.

in a flame, but none will flash. Compounds containing tricresyl phosphate as a plasticizer are flame-resistant.

GAS DIFFUSION. Plasticized PVC compounds are more resistant than rubber to diffusion of gases. Comparative diffusions are listed below:

17-ounce rubber-coated fabric: Hydrogen diffusion per square yard in 24 hours, 0.27 cubic foot.

5.6-ounce PVC-coated fabric, same fabric base: Hydrogen diffusion per square yard in 24 hours, 0.079 cubic foot.

OIL AND SOLVENT RESISTANCE. Plasticized PVC compounds are remarkably resistant to the actions of mineral and vegetable oils and to various chemicals classed as solvents. At ordinary temperatures, the

compounds may show a tendency to lose weight and shrink slightly. As the temperature is increased, shrinking becomes more noticeable because of the extraction of some of the plasticizer. The compounds also show a slight increase in stiffness.

Solvents for PVC

Methyl ethyl ketone is the most common solvent for PVC resin. When higher ketones such as cyclohexanone are mixed with this solvent, a higher concentration solution may be obtained.

Electrical Properties

The PVC plastics are nonconductive and are useful as insulating materials. The dielectric strength may exceed 1,000 volts per 0.001 inch

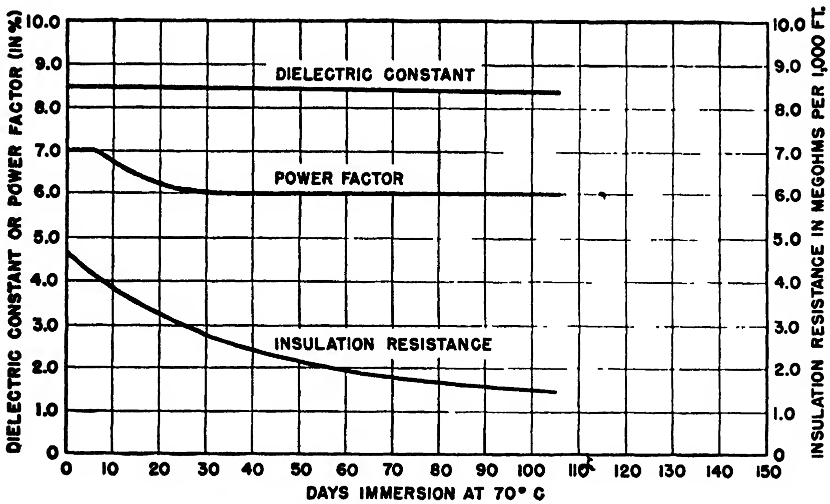


Fig. 3. Electrical properties of a typical PVC compound during long-time immersion in water at 70°C. Tests were conducted on samples of solid No. 14 wire having $\frac{1}{32}$-inch insulation.

of thickness. By proper compounding, power factor, insulation resistance, and dielectric constant sufficient for many communication and power-transmission cable requirements are obtained. Insulating compounds have been approved for continuous use at 80°C (176°F). Corona-cutting resistance is extremely high.

Electrical characteristics of plasticized PVC remain virtually unchanged throughout prolonged exposure to severe atmospheric condi-

tions or immersion in water for longer than three years. Insulation such as that on wire will withstand severe handling during installation and use, and it need not be so heavy as rubber or most other kinds of insulating material. Because of thinner insulation, more wires can be pulled through a conduit when they are covered with PVC than when conventional insulating materials are used.

It is not practicable to list electrical characteristics for all possible compounds, but Table 5 gives the properties of three typical PVC plastic compounds.

TABLE 5. ELECTRICAL CHARACTERISTICS OF PVC COMPOUNDS

Property	*Cycles*	*Temp., °C*	*Compound No.*		
			1	*2*	*3*
Dielectric constant... .	60	25	.	4.1	6.8
	60	45	. ...	6 8	9.8
	60	70	13.8	8.0	10.7
	1,000	25	....	3.4	5.1
	1,000	45	......	5.3	8.3
	1,000	70	13.0	7.6	10.0
Power factor. . .	60	25	....	11.7	14.8
	60	45	....	10.5	16.1
	60	70	4.8	8.8	79.4
	1,000	25	....	7.9	15.5
	1,000	45	.... .	15 6	13.0
	1,000	70	4.1	5.2	· 14.1
Resistivity, ohm-cm.	.....	25	.	4×10^{14}	1.8×10^{12}
		45		$5\ 4 \times 10^{12}$	4.7×10^{10}
		70	65×10^{9}	$7\ 8 \times 10^{10}$	2.5×10^{9}

Change in electrical properties of a typical PVC plastic compound during immersion for more than 100 days in water at 70°C (158°F) are shown in Fig. 3. Samples were No. 14 copper wire with $\frac{1}{32}$-inch insulation.

Electrical properties of PVC plastics are affected by the kind or amount of plasticizer, stabilizer, and pigment used in the compound. Thus the presence of a stabilizer may give the compound an initial resistivity of 100,000 megohms per centimeter, while without the stabilizer the resistivity of the same compound is only 1,300 megohms per centimeter. Some pigments decrease initial resistivity in proportion to the amounts added, while others cause first an increase and then a decrease. Presence of impurities in a compound may have a very marked effect on electrical properties. Because of the various factors involved, the poten-

tial user of a PVC plastic in connection with electrical installations should consult the manufacturer's technical men for specific recommendations.

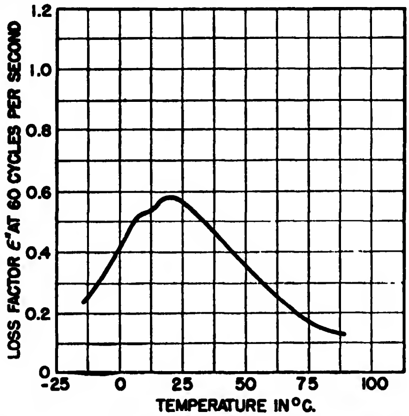


FIG. 4. Loss factor at various temperatures for a typical PVC compound.

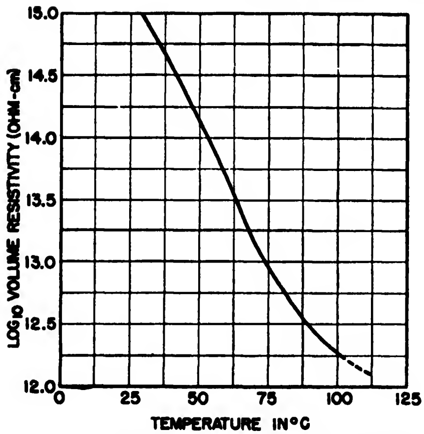


FIG. 5. Volume resistivity at various temperatures for a typical PVC compound.

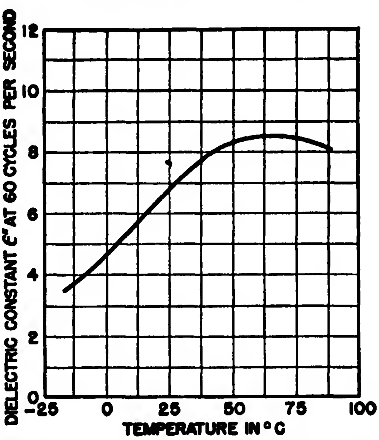


FIG. 6. Dielectric constant at various temperatures for a typical PVC compound.

Aging of PVC plastic compounds has little effect on electrical properties up to 158°F. Table 6 shows effects of aging on volume resistivity.

TABLE 6

Days' Aging at 158°F	*Volume Resistivity at 158°F, Ohm-cm*
0	30.6×10^{12}
20	28.7×10^{12}
32	25.6×10^{12}
77	17.5×10^{12}
116	11.0×10^{12}
134	12.3×10^{12}

A Typical PVC Plastic

Products made from plasticized vinyl chloride polymers by The B. F. Goodrich Company are identified by the trade-mark "Koroseal." In this chapter, Koroseal flexible material and the various articles made from it will be considered as a typical family of PVC compounds. There are other PVC plastics in the same group (see Chap. 1); and because of the unlimited possibilities of compounding and processing, these may in some instances be similar or identical, in others vastly different. The situation is much like that concerning rubber: Basically, a specific rubber is the same, no matter what its source, but manufacturers may compound it in their own ways to produce a wide variety of products—which are all "rubber." The same is true of vinyl chloride polymer plastics.

Koroseal flexible material is manufactured from vinyl chloride polymers derived from water, salt, coke, and limestone or from water, salt, and petroleum—plus a plasticizer and other ingredients.

Forms

The resistance of Koroseal flexible material to aging, acids, alkalies, and other corrosive chemicals and to abrasion and rough handling; its electrical properties; its possible forms and colors; and its thermoplastic properties, all combine to make it a material of particular interest to the product designer. Its cost is initially greater than that of rubber compounds, but often its superior properties make it ultimately cheaper.

Molded Articles. This flexible material can be formed by injection molding into an infinite variety of shapes limited only by mold design. Mold shapes and compound hardness range are about the same as for rubber compounds. The injection process is used because it is faster than the compression method, the latter requiring cooling of a hot mold until the thermoplastic contents become rigid enough to be removed.

Extrusions. In the making of tubing, gasket strips, and similar continuous forms, the material is extruded in much the same manner as rubber compounds of comparable elastic properties. It will take a polished, wear-resistant finish that cannot be produced on either crude or American rubber. It need not be vulcanized, but only cooled, and therefore it can be processed more cheaply than extruded rubber.

Koroseal tubing is used extensively for handling beverages and for chemicals other than those classed as harmful to the material (see Table 4). Since properly formulated tubing neither deteriorates nor contaminates electroplating solutions, it can be used for insulating plating-rack contact wires to prevent waste of electric current and useless deposit

rial, forming a tight joint between tubes and tape. Finally, the covering is fused into a homogeneous unit.

Koroseal tubing has a property that often saves installation time, particularly in laboratory work. Two ends can be joined by holding them for a few seconds against a metal plate that is hot enough to melt them and then bringing them together and holding them until the mate-

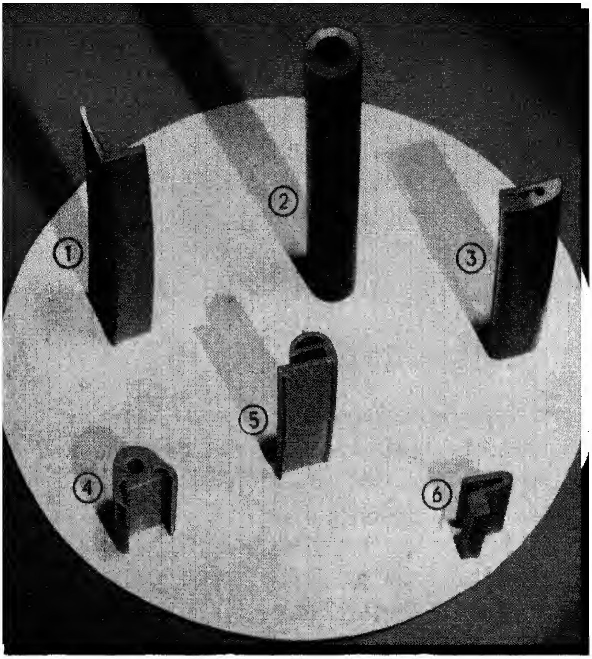


FIG. 7. Complicated plastic or rubber extrusions can be duplicated in Koroseal compounds. Some simple forms are (1) protective angle strip, (2) beverage tubing, (3) bumper strip for a vacuum cleaner, (4) decorative molding for train coaches, (5) refrigerator-door gasket, and (6) metal-panel sealing strip.

rial cools. Or the heating can be done with a match. Usually, on a tension test, the tubing will break outside of a properly made joint.

Characteristics of Koroseal No. 116 tubing are listed below:

Size range: Inside diameter, $\frac{1}{8}$ to $\frac{3}{4}$ inch; wall thickness, $\frac{3}{32}$ to $\frac{3}{16}$ inch.

Tolerance, all sizes: $\pm\frac{1}{64}$ inch on inside diameter and on wall thickness.

Length: Continuous. Normally carried on reels.

Durometer hardness at 85°F: 70 to 78.

Specific gravity: 1.31.

Color: Dull black.

Working pressure: 50 psi at temperatures to 120°F.

Vacuum service: Superior to rubber of same wall thickness.

Gas diffusion resistance: Practically impermeable.

Limitations: Not suitable for use in contact with food. For such service, special compounds are made.

Temperatures above 150°F cause softening.

May cold-flow slightly; continuous use under pressure may cause slight increase in tube diameter.

FIG. 8. Liquid soup can be packaged in a cardboard container when it is first surrounded by a bag made of Koroseal film.

SHEETS. Koroseal sheet can be made in more uniform thickness than is possible with rubber. Thin films, useful for packaging foods and numerous other products, range in thickness from 0.001 to 0.0035 inch; calendered sheeting, from 0.004 to 0.030 inch in widths to 54 inches and from 0.030 to 0.250 inch in 36-inch width. These various forms are all noteworthy for their high tensile strength. They may be translucent, opaque, or in any color. Lettering and attractive designs can be printed on them, or they may be given an embossed surface design.

The degree of opacity of films covers a wide range and extends all the way from the transparent cast film to the wholly opaque. In this respect, the plastic is superior to rubber, which cannot be made to approach the transparent except in a few compounds of limited practical use.

Koroseal sheet and Koroseal coated fabric or paper can be embossed to produce an unlimited range of surface textures. Leather texture can be

reproduced very realistically, and the reproduction will outwear leather three or more times! Novel and beautiful two-tone effects are created on textured surfaces. One such finish has low areas of one color, high areas of another.

COATED PAPER AND FABRIC. When the plastic coating is applied to one or both surfaces of paper or fabric, materials of virtually unlimited possibilities result. Coated paper is used to package food and nonfood products. Because of the resistance of such paper to most liquids, paper bags or cardboard containers lined with it can be used for holding oils. liquid foods, and many chemicals. Coated paper that has a natural calendered finish is smooth and shows no distinctive texture. By embossing the coating with suitable dies, practically any texture can be produced. Paper so textured is useful for covering luggage, books, wall surfaces, etc., and coated fabrics for upholstering furniture, for making luggage and handbags, and for numerous other purposes. The wear resistance of Koroseal coated fabric is so great that a traveling bag covered with it will look new after several months of hard usage; all that is necessary to clean the surface is to wash it with soap and water. The clear plastic can be used to impart these properties to any paper or fabric without changing the color or design or modifying the surface texture greatly.

Thickness range of the coating on paper or cloth is ordinarily from 0.0015 to 0.002 inch but may exceed 0.015 inch.

TAPE. Koroseal tape is used widely as insulation, especially in electroplating. Two types are made:

1. Koroseal Tape RX. Thickness, 0.014 inch. Width, ¾ inch. Roll weight, 1 pound (170 linear feet of tape). Color, black. Use: For covering portions of plating racks that are to be isolated from plating solutions. Tape is applied like ordinary friction tape, no special preparation of rack surface being required. It should be held under slight tension during wrapping, and edges should overlap ⅛ to ¼ inch. After wrapping, tape may be fused into homogeneous mass by heating in an air oven for 1 hour at 300°F. If a portion of the wrapping is damaged, the spot can be covered with new tape, which is then fused into the old wrapping.

2. Koroseal Tape MX. Thickness, 0.005 inch. Widths, ¾, 2, 6, and 36 inches. Color, gray. Otherwise like RX. This tape is intended for masking purposes, to keep plating solutions or other chemicals from areas it covers. Thinness and elasticity permit it to be fitted snugly around irregular shapes.

SOLUTIONS. In solution, Koroseal flexible material is known by the trade-mark Korolac. Korolac RX solution is designed for coating metal surfaces where it is desired to prevent metal from adhering during

electroplating. The solvent evaporates, leaving a translucent coating about 0.0015 inch thick that resists most chemicals, including chromic, sulfuric, and nitric acids. The coating is not so sturdy mechanically as Koroseal tape, but damaged spots are easily repaired by applying new Korolac. Plating racks can be covered by dipping or brushing. They should be clean and free of sharp corners and edges. For general purposes, four or more coats are recommended, each being permitted to dry thoroughly. Drying may be at room temperature or in an air oven at 150°F.

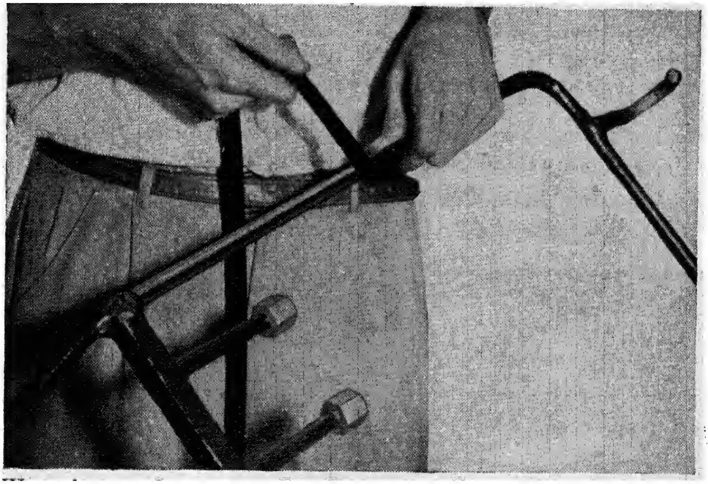


FIG. 9. Wrapping an electroplating-tank rack with Koroseal tape to produce a corrosion-resisting covering that acts also as insulation.

COMBINATION COVERINGS FOR PLATING RACKS. When there are no facilities for fusing Koroseal tape, the following procedure may be used: (1) Apply two or three coats of Korolac RX to cleaned metal, drying each thoroughly. (2) Wrap coated area with Koroseal tape RX, overlapping edges ⅛ to ¾ inch. (3) Apply one or two coats of Korolac RX to tape surface, drying each coat thoroughly.

MOLDING COMPOUND. Koroseal flexible molding compound is in extensive use in the manufacture of plaster casts and plastic objects and in other molding operations. Considerable work in the technique of use has been done by the Perma-Flex Mold Company of Columbus, Ohio.

The molding compound does not warp, expand, contract appreciably, or harden over a period of use or time. Mildew, water, acid action of melted alum, alkalinity of plaster, setting heat, and ordinary handling have no detrimental effect on it. The mold resembles one made of vulcanized rubber or gelatin and retains all the minute details of the pattern.

Different grades are available. Number 15 is the softest; No. 6 the stiffest and toughest. Further stiffness can be produced by addition of a hardener to No. 6.

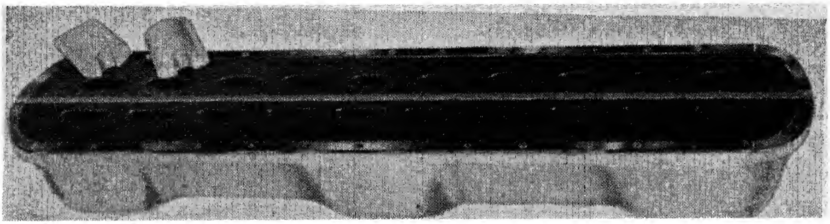


Fig. 10. This large, 20-cavity industrial mold, made of Koroseal flexible molding compound, was used in the manufacture of nonmagnetic cases for land mines.

Additional Characteristics of Molds Made of Koroseal Molding Compound. They do not deteriorate like rubber and are not affected by grease, mineral, or vegetable oils. Plaster does not stick to them after setting, as it does to rubber. No lubricants or parting compounds are

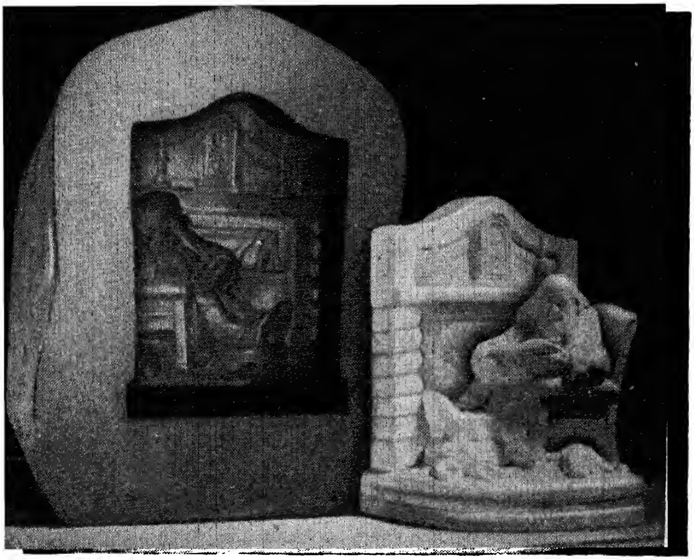


Fig. 11. A plaster book end having undercut details, and the Koroseal mold in which it was produced.

required other than simple rinsing in solutions such as Perma-Flex Mold Dressing to reduce pinholes and air-bubble defects and produce maximum detail. No surface treatment is required for casting concrete. Pieces with back draft or undercut may be cast to close dimensions in one-piece molds. Tolerance attainable is ± 0.1 per cent. Molds are suitable for

casting waxes and metal alloys such as Cerrobend and Cerrosafe, which melt below 200°F. The molding material is liquefied by heating and flows at 260 to 325°F.

Making Molds. Melt the compound in a glass, vitreous, or enameled-metal container. In the liquid state, the material reacts with metals. Melting should be done under a hood or where fumes may be otherwise removed. Use a thermometer or pyrometer for determining temperature; overheating decomposes the material. In practice, the most suitable melting equipment consists of vessels supplied at the top with radiant heat from lamps or resistance coils and with bottom heat from sand or oil baths, asbestos pads, or electrical-resistance units and thermostatically controlled. In many cases, ordinary electric kitchen roasters having enameled linings will work well. The radiant heat may be supplied by infrared lamps or resistance units placed above the roaster. Frequent stirring during melting will expose unmelted lumps to radiation. After melting, the compound should be covered with an insulating lid for 10 to 20 minutes to permit gas bubbles to work out. An alternate method is to place the compound in a covered oven-glass container and heat in a kitchen oven at a maximum of 350°F.

The molds can be remelted, and the compound used over and over.

Pattern or Model. Preparation of models around which the Koroseal compound is to be cast varies with the model material.

Nonporous models such as metal, glass, china, and marble: Heat slowly to about 200°F. Coat lightly with mineral oil such as 10-W, 3-in-1, or Finol. Suspend the model inside a shell made of metal or non-porous material, and pour the compound around it. When cooled, preferably by standing overnight, peel the mold off the model, cutting the compound where necessary to facilitate removal. The mold is generally placed in the supporting shell whenever a cast is to be made, to prevent distortion.

Plaster, Hydrocal, and other gypsum models present difficulties because of their porosity and water content, which cause formation of bubbles in the heated compound. However, successful molds can be made by careful manipulation and with the aid of a solution such as Perma-Flex Sealer, which is applied to the model before casting the molding compound around it. Molds should not be cast around models that are painted or lacquered. Some modeling clays will melt when they come into contact with heated materials. Water-mixed clays sometimes can be used successfully if they are first coated thickly with Vaseline or oil.

Lost-wax Process. This ancient casting method can be modernized by using Koroseal flexible molding compound in the following manner: (1) Cast the compound around the master model to form a mold. (2)

Pour suitable wax into the mold, keeping wax temperature below 200°F. (3) Remove wax cast and pour plaster around it, after installing suitable gate and riser casts made of wax. (4) When the mold plaster has dried, place it in an oven and melt out the wax. (5) Pour metal into cavity formed by wax; and when it has cooled, break away the plaster.

High-temperature Metal Molding. In this process, the intermediate pattern is made of plaster instead of wax. (1) Cast Koroseal molding compound around master pattern. (2) Use the resulting mold to make a plaster cast. (3) After plaster is thoroughly dry, shellack, lacquer, or otherwise treat the surface to seal the porosity, and apply a thin coating of oil. (4) Use this cast as a pattern for making a two-part or similar female mold out of plaster. (5) Cast metal in the plaster mold. The same Koroseal master mold can be used to make a wax or a plaster intermediate pattern.

LIMITATIONS. *Temperature.* Being thermoplastic, Koroseal flexible material and similar polyvinyl plastics are softened by heat. Tensile strength, hardness, and elongation vary almost exactly with temperature, decreasing as the temperature rises. Normal useful temperature range is −40 to +150°F. Within this range, the material may be considered permanent. Special compounds may be devised for temperatures outside this range.

Chemical Resistance. Koroseal materials are not recommended for constant, complete immersion in the following:

Acetic acid, glacial or highly concentrated solutions
Aliphatic or aromatic ketones
Aromatic amino compounds
Gasoline or other solvents
Organic compounds containing chlorine or nitro groups

VINYL CHLORIDE POLYMER FORMS

BASIC RESIN. This is available to industry in the form of a white powder. One type is a polymer of vinyl chloride; a second is copolymer of vinyl chloride and vinyl acetate; a third is a copolymer of vinyl chloride and vinylidene chloride. The resins are compounded with plasticizers, pigments, and other materials to produce elastomers. Examples of PVC resins are Geon 101 (polymerized vinyl chloride) Vinylite VYNW (copolymer of vinyl chloride and vinyl acetate), and Geon 202 (copolymer of vinyl and vinylidene chlorides).

PLASTICIZED PVC. The basic resin is compounded with various plasticizers, pigments, and other ingredients. It is usually sold in the form of granulated particles or milled sheets, *e.g.*, Geon plastics.

LATEX. Plastic latex made with polyvinyl resins is used in impregnating or coating fabrics, wire, yarn, string, and thread. The resin and plasticizer are combined in each particle of the latex suspension; *e.g.*, Geon plastic latices.

FINISHED PLASTICIZED VINYL CHLORIDE POLYMER PRODUCTS. These are materials or parts that are sold ready for use in industry, the home, or elsewhere. Usually there are so many problems of manufacture involved in the production of a particular part that the purchaser finds it advantageous to consult the manufacturer while the project is still in the paper stage.

The following list contains some of the more important industrial, laboratory, and consumer items made of Koroseal flexible material and similar PVC materials:

Acid containers
Linings for tanks, barrels, drums
Grommets and gaskets
Tubing for handling beverages, milk, photographic solutions, blood plasma, etc.
Refrigerator gaskets
Window-glazing strips
Sealing strips for joints in concrete, metal tile, etc.
Hose for water and chemicals
Water-tank valve balls
Book covers
Upholstering fabrics of unlimited texture and pattern
Food-packaging sheet material
Liners for bottle caps and similar covers
Laboratory-apron material
Industrial protective clothing and raincoats
Protective covers for instruments, photographic equipment, etc.
Shock-absorbing inserts for shaft couplings
Decorative molding and bumper strips
Compression cups for fruit-juice extractors
Pipe covering to prevent damage in acid soil
Fruit-tree fumigation tents and oxygen tents
Hospital sheeting
Molding material
Coated paper for lining containers, imitation leather, etc.
Industrial gloves
Bellows for service where there is oil or grease
Valve disks and pump diaphragms
Grease gun cups and seals

Sponge for padding machinery, etc.
Storage battery cases, jars, and separators
Electrical connecting plugs and caps
Chemical dippers and other containers
Pocketbooks, luggage, and instrument cases
Bags for garments, blankets, etc.
Film for seal-packaging of machine parts, tools, etc.
Automotive body strips
Belts for clothing, wrist-watch straps
Shower curtains, bowl covers, ironing-board pads
Upholstery
Aprons
Shoe soles and uppers
Raincoats
Umbrellas
Table cloths
Baby pants

MAKING SEAMS. Koroseal flexible material and similar vinyl chloride polymer plastics, being thermoplastic, are softened by heat. This property is a valuable one in the joining of pieces of sheet material for making covers and pouches, sealing packages against air and moisture, joining pieces of tubing, and fusing taped coverings into homogeneity.

Although it is possible for anyone to make a sealed joint in Koroseal sheet, coated paper, or fabric with a hot iron, a soldering copper, or a piece of metal heated in a flame, the production of uniformly sound joints requires some practice, proper equipment, and the development of a definite technique. Considerable development work has been done on automatic sealing machines that employ such elements as heated rollers or strips. One difficulty is that heat is applied from the outside and must pass through all of the material thickness before it reaches the actual surfaces to be joined. Another difficulty is that pressure should be maintained on the joint until the plastic cools sufficiently to preserve the seal (below 100°F).

All sealing involves the elements of time, temperature, and pressure. The temperature ranges from 275 to 325°F. Pressure should be the minimum necessary to maintain good contact.

One type of sealing machine (Sav-Way Industries, Detroit, Mich.) employs two stainless-steel tapes that move as synchronized belts, carrying the plastic sheeting along between them. Heat is applied at one point until a seal is formed, and then the tapes move far enough to cool before releasing pressure on the seam.

Electronic sealers, which by means of high-frequency current generate

heat at the inner faces of the film layers, are in many respects ideal for forming seals in thermoplastics, particularly in thicknesses of 0.004 inch and above. The sealing electrodes are always cold, and therefore the joint cools almost instantly after being made. A seal can be completed in two 0.005-inch sheets in less than 3 seconds, as compared with more than 5 minutes with some types of heated platens. Curved and circular seals are feasible. Flat dies (electrodes) that come together like any press platens are used in some types of electronic sealers (such as those made by Radio Receptor Corporation, New York, and the Illinois Tool Works, Chicago, Ill.). Other sealers employ roller electrodes, between which the material moves much as it would through a sewing machine (such as sealers produced by Union Special Machine Company, Chicago, Ill., and the Singer Sewing Machine Company, New York).

Chapter 24

CASE HISTORIES

The Case of the Jittery Tenants

The Problem. A company with a mass of important work to do arranged to move its laboratory into the building where its offices were situated. When other tenants heard that the laboratory equipment would include a 3-ton press, they joined forces in voicing their objections. Any-

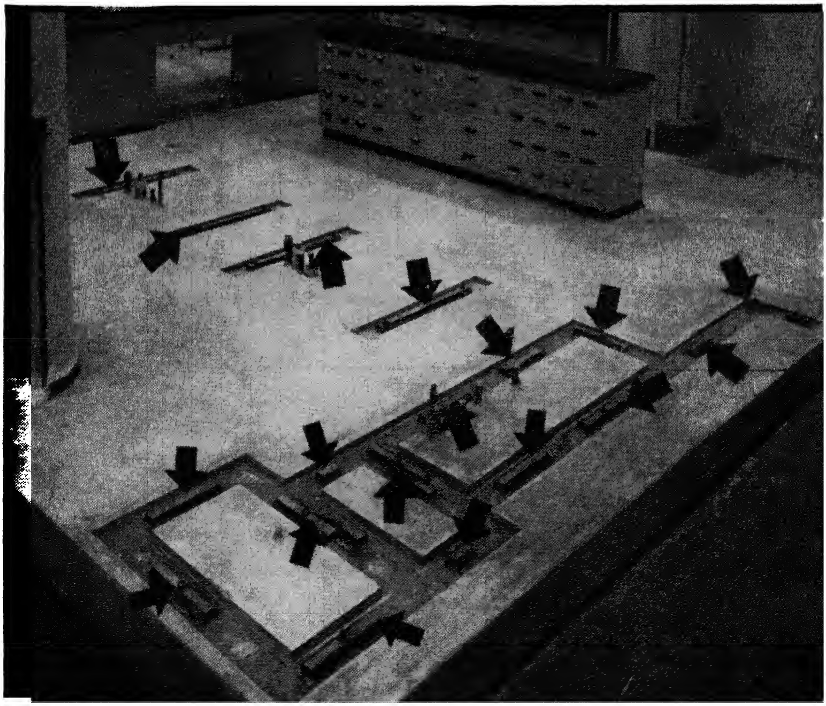


Fig. 1. Arrows indicate rubber mountings that prevented vibrations originating in laboratory equipment from reaching structure of an office building.

one knows that a stamping press or any other kind of press that large will shake a building as a terrier shakes a rag doll, they declared. But the company that planned the industrial laboratory was not disturbed

by the objections. Its officials knew that it was absolutely necessary to have the laboratory near the offices, to save time in carrying out the vital work. Also, they knew something about big presses that the other tenants did not know.

THE SOLUTION. Before the big press was installed, the floor was carefully prepared and a score of rubber vibration insulators were bolted in positions carefully calculated by the engineers. Then the press was placed on the insulators, its 3-ton mass actually floating on the resilient rubber. Now it was free to vibrate as much as it pleased, yet the rubber would prevent the disturbances from reaching the floor and the rest of the building.

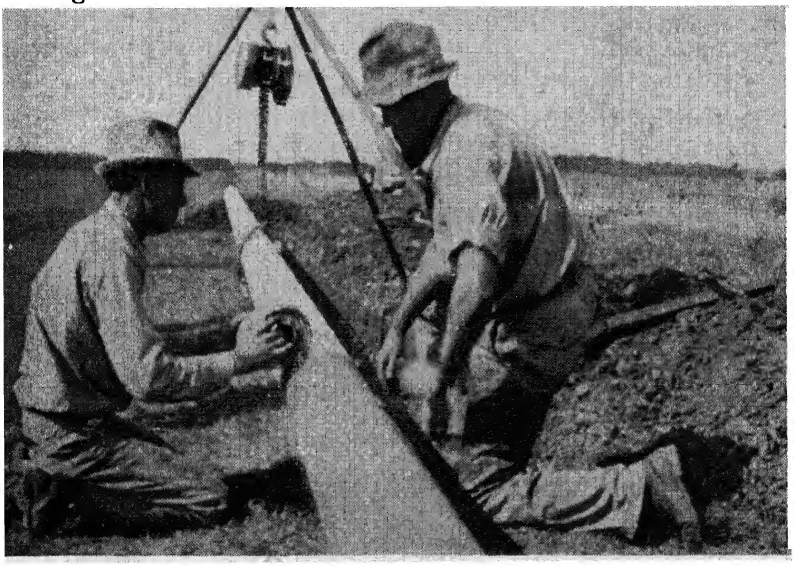


FIG. 2. Making a mummy out of an oil pipe line by wrapping it with Koroseal coated cloth.

The rubber-mounted press operated for many months without shaking even the suspicion of a squawk out of the other tenants.

THE PIPE THAT BECAME A MUMMY

THE PROBLEM. A Texas oil pipe line was being destroyed by "hot spots"—areas of soil so acid that it literally ate up any metal buried in it. So vicious was the soil's attacks that large sections of costly pipe had to be replaced each year.

THE SOLUTION. Engineers decided to take a hint from the undertakers of ancient Egypt. They wrapped long sections of the pipe tightly with cloth coated with Koroseal flexible synthetic. Then they painted the

wrapping with a Koroseal solution, to fill the seams and other spots where moisture and acid might enter. Finally, they buried the wrapped pipe in the hot-spot soil.

A year went by, and the pipe still did its work without a sign of leaks. Two years—and the engineers dug down to their mummy to see what was happening. They found that nothing out of the ordinary was taking place—that the pipe was as unharmed by corrosion as the day they had "embalmed" it.

The Case of the Kidney Network

The Problem. The tedious routine of slicing tissue into thin sections and studying them with a microscope used to be the only practical way for biologists and medical researchers to study the complex blood vessel network in the human kidney. Then someone got the idea that perhaps the kidney network could be reproduced in rubber.

Fig. 3. Rubber reproduction of blood-vessel network in a human kidney.

THE SOLUTION. Research technicians having wide experience in rubber were consulted and said they thought that the job could be done with a certain American-rubber latex which flows like milk. Just force the latex into the kidney until all the vessels were filled, then dissolve away the kidney tissue, leaving the rubber. But the latex proved too thick to enter the smallest passages. It clotted easily, and in slender tendrils it might be attacked by the acid used to dissolve the tissue. So the rubber technicians developed a thin, nonclotting, acid-resistant latex that did the trick. With it, a faithful model of a kidney's blood system could be reproduced in rubber. Students could actually see the complex system they were trying to understand. Research in kidney diseases could progress more rapidly—all because there were some rubber technicians who knew how to modify latex. The kidney-injection technique might be adapted to various other purposes—such as the studying of ducts and vessels in other kinds of animal and plant tissues.

GAS ROBE FOR A TREE

THE PROBLEM. Fruit growers knew what would subdue the California red scale that was attacking their trees and fruit: Put a bubble of poison gas around it for a while. But the cure was not quite so simple as that, for the gas had a way of leaking rapidly from beneath canvas tents placed over individual trees before it had finished with the scale. Coated fabrics of various sorts were tried, but the California sun cracked them, causing leaks.

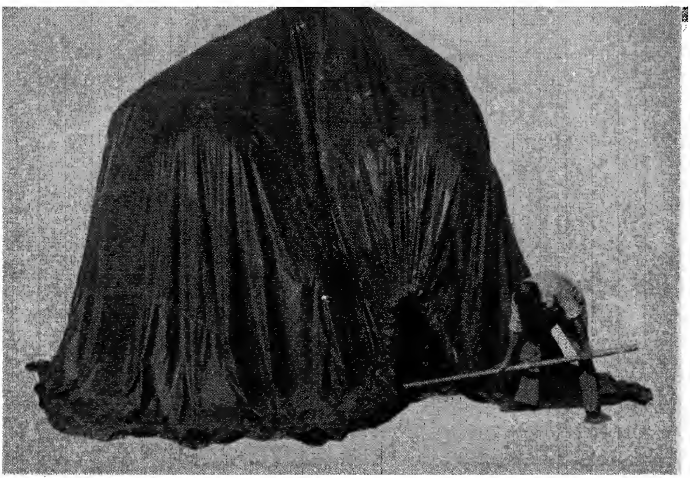


FIG. 4. A tree under this Koroseal coated tent is being fumigated to kill insects.

The Solution. The fruit growers' problem finally got to Akron and was placed before technicians who were familiar with Koroseal flexible material, a plasticized PVC that refuses to be ruffled by water, air, most chemicals, and even California sunlight. The technicians built a fumigation tent of Koroseal-coated cloth and shipped it to California—where it has been fighting scale for more than two years without a sign of cracking or leaking. This tent enables the scale on a tree to be killed more completely with only one-third of the gas required by a canvas tent.

The Rubber That Behaves Like Glass

The Problem. The quality of industrial glue is judged by smoothness and clearness of the flakes. This glue used to be made by pouring a hot mixture on glass plates, letting it cool, then breaking the film into flakes. Someone got the idea of speeding the process by pouring the glue on a moving rubber belt and slicing it off with a moving knife. The idea was perfect—except that the glue came off cloudy instead of clear, and cloudy glue, to many a glue buyer's mind, is definitely inferior.

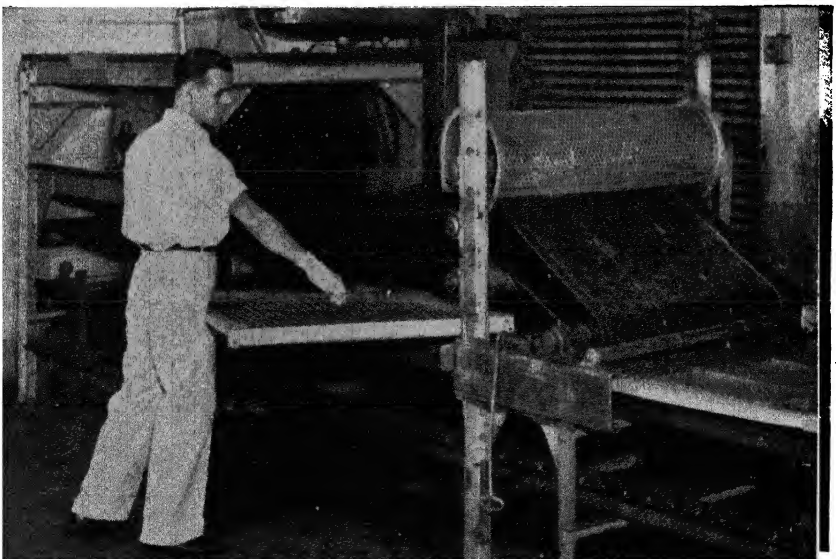


Fig. 5. Making flake glue on a rubber belt.

The Solution. To a rubber manufacturer went the glue maker. "Can you make us a rubber belt that is as smooth and firm as glass?" he asked. The rubber company technicians said they would try. They not only developed a rubber belt having a surface that produced glue flakes as clear and glossy as ever, but they built into it sufficient heat

resistance to make it unharmed by the molten glue, raised the belt edges so the glue would not run off, and held the belt thickness to such small variations that the knife could cut the glue without touching the belt. Thus did rubber clear up another tricky industrial problem.

THE CASE OF THE HIGH-SPEED ONION SEEDS

THE PROBLEM. A large seed company was handling tons of tiny onion seeds by blowing them with compressed air through galvanized steel

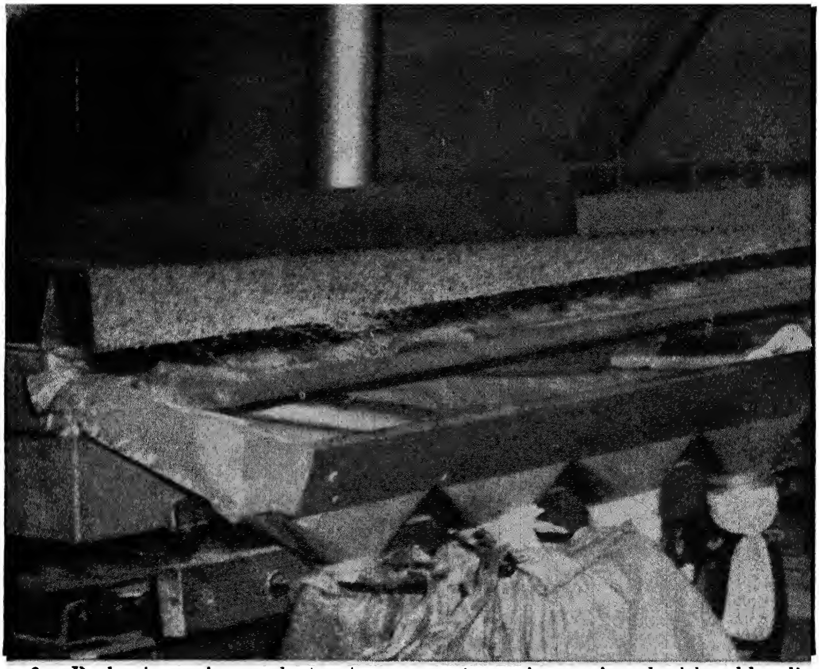


FIG. 6. Packaging onion seed after it emerges from pipe equipped with rubber-lined elbows.

pipes. The seeds, even though somewhat delicate, traveled so fast that they literally "seedblasted" their way through the pipe elbows, damaging themselves and making periodic elbow repairs necessary.

THE SOLUTION. Officials of the seed company had heard about rubber-lined chutes and similar products and wondered if rubber could help them handle onion seed more efficiently. The engineers of a rubber company thought so and then proved their theories by developing a special "onion seed" rubber compound so soft it will not harm the tiny seeds that impinge against it, yet so tough that the hard, sharp seed coats will not

cut into it. Elbows made of this compound showed no sign of breakdown after carrying 78,000 pounds of onion seed during three seasons, whereas metal elbows wore out in one season. Furthermore, the seed was found to be of improved quality because of freedom from "elbow damage."

Rubber Solves a Sugar-beet Problem

The Problem. There was a time when seven processing steps were required to convert a sugar beet into granulated sugar. The last four

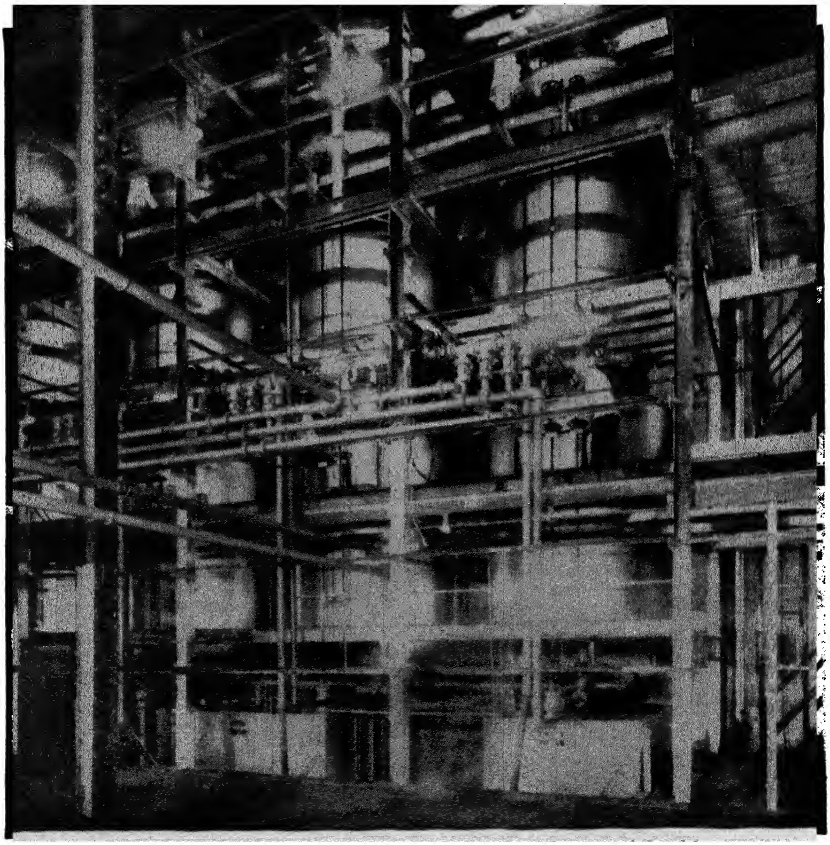


Fig. 7. These tanks in a beet-sugar factory are lined with a special rubber compound.

steps were concerned with making the sugar white instead of brown. Then a sugar company found a way of eliminating one of the final steps, the cleaning being done in a system of tanks. Also, the new process increased the yield 6 per cent, and the sugar was sweeter than before. It worked out well on the blueprints; but when the new system was put

into operation, the sugar came out discolored instead of white because of the influence of metal in the tanks. Lined tanks were tried, but still the sugar was tinted.

The Solution. The sugar company took its troubles to a rubber manufacturer who for years had been lining railroad tank cars, acid pickling tanks, and other vessels. The rubber technicians went to work and came up with a cream-colored rubber lining that has no effect on the complexion of beet sugar, imparts no taste, is easily cleaned, and lasts for years. Thus once more was demonstrated the seemingly unlimited versatility of the art of rubber compounding.

The Case of the Soft-drink Mixer

The Problem. A nickel-in-the-slot soda fountain was developed to dispense soft drinks without the assistance of a human soda jerk. The process of measuring sirup and water and carbonating the drink required a shaft whirling at high speed in bearings submerged in water where they could not be oiled. The manufacturer tried every kind of conventional bearing, but rapid wear let the shaft whip and cause the gas to escape.

The Solution. The manufacturer had heard of rubber bearings lubricated by water and used around the propeller shafts of marine vessels, the shafts of centrifugal pumps, cutter head shafts of dredges, and similar equipment. Could he get some small bearings like those, for his drink-mixing machine? The rubber manufacturer who made the big bearings turned out tiny duplicate ones for the automatic soda fountain. Hundreds of the machines were then installed in factories and army canteens—one of them mixed 33,800 drinks in one month—and not one of them developed bearing trouble. Water-lubricated rubber bearings are finding similar new applications in numerous kinds of industrial equipment. (See pages 401–414.)

Rubber Collars for Underground Necks

The Problem. Oil wells are drilled with bits attached to the lower ends of spinning pipes that sometimes reach into the earth for 2 miles. As a bit eats its way downward, a steel casing—another pipe—is forced down the hole to keep its wall from caving. Thus there is one pipe spinning inside another, a condition that results in rapid wear when steel is allowed to rotate against steel. Someone got the idea of snapping heavy rubber bands on the spinning pipe at intervals of 20 to 30 feet to reduce wear on the metal. But the bands had to be slipped over the

pipe ends, a time-consuming operation, and they developed a habit of loosening, slipping down, and letting the pipes wear as fast as ever.

THE SOLUTION. Rubber company engineers were given the chore of developing a casing guard that would have none of these shortcomings. They fashioned semicircular metal ring segments hinged together in pairs like the leaves of a door hinge. They covered both the inside and outside

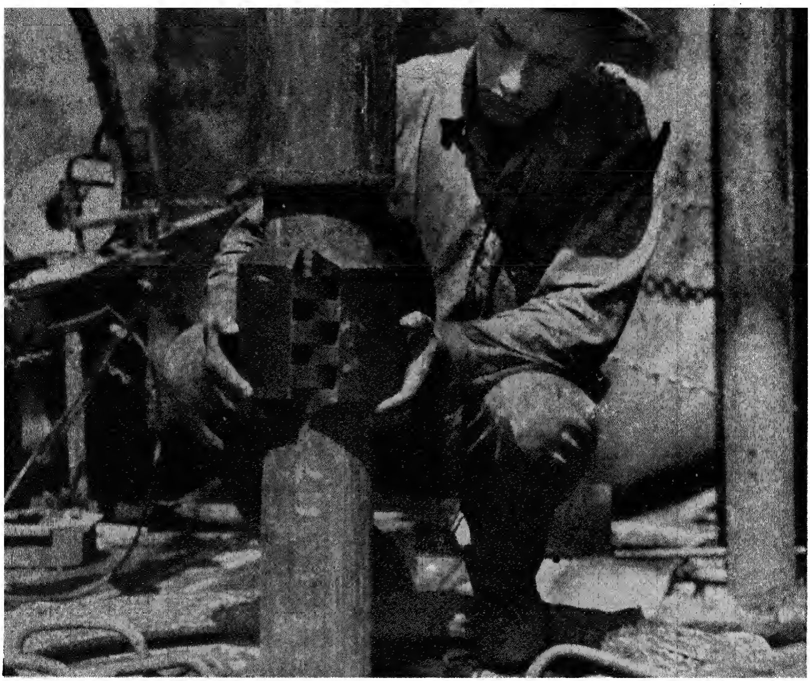


FIG. 8. Fitting a split rubber collar around a pipe used in drilling an oil well.

surfaces of the semirings with tough rubber. When two such pieces are fitted around the pipe and a wedge-shaped pin driven through slots in the metal to draw the open ends together, the inside rubber covering grips the pipe so tightly that slipping becomes impossible, while the outer rubber becomes a cushioned, water-lubricated bearing surface rotating smoothly inside the casing.

THE CASE OF THE PIPE-EATING COAL

THE PROBLEM. One of the largest power plants in the country had installed powdered-coal equipment for firing its boilers. The coal, blown through pipes as if it were so much oil, could be controlled easily, did not

clog the feeding mechanism, and had other advantages, but it had the costly habit of eating through the steel pipes as if they were so much cardboard.

THE SOLUTION. Power-plant officials took their worries to a rubber manufacturer whose engineers had been licking tough gravel-handling problems by lining the chutes with a special rubber armor. This type of lining was applied to pipes used for conveying the powdered coal, and

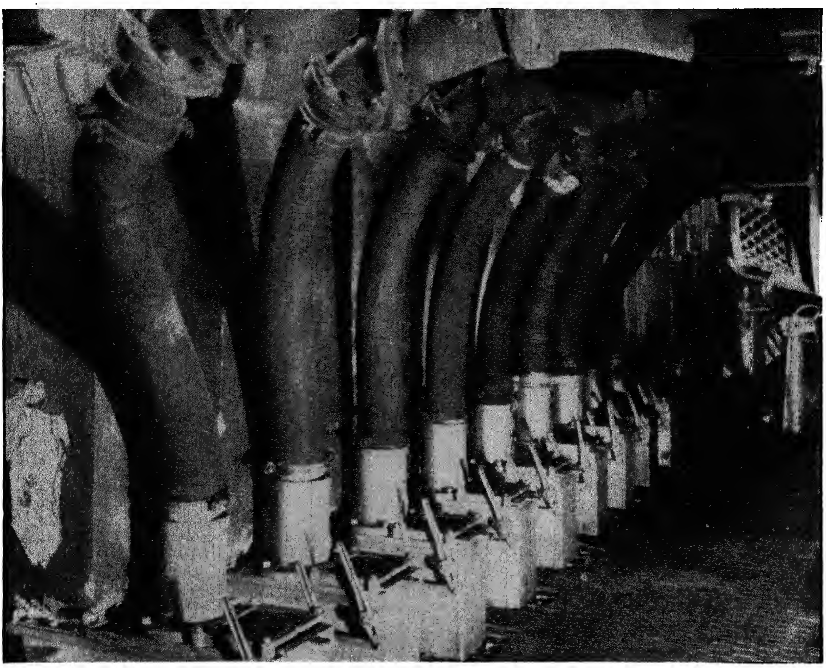


FIG. 9. Powdered-coal installation in power plant where rubber-lined pipe and rubber hose cut maintenance costs.

the power plant's troubles disappeared. All-metal pipes used to last only a few months; their rubber-lined successors carry coal dust year after year without so much as a pause to interrupt power generation.

THE SUGAR THAT GUMMED THE WORKS

THE PROBLEM. It used to be the practice to load raw sugar into jute bags in Hawaii, pile the bags in the hold of a ship, and then carry them off again when the vessel reached the mainland. Then the war cut off the jute bag supply, and sugar had to be shipped "loose." But how to handle the stuff? Rubber conveyor belts seemed like the answer, for

they could snake the sugar directly from the warehouse to the ship's hold. Belts were installed—but no one had reckoned on sugar dust, which settled on the rollers supporting and guiding the belts and turned into a molasseslike gum in damp weather. When the conveyor was stopped, the molasses glued the belt to the rollers so firmly that, as it

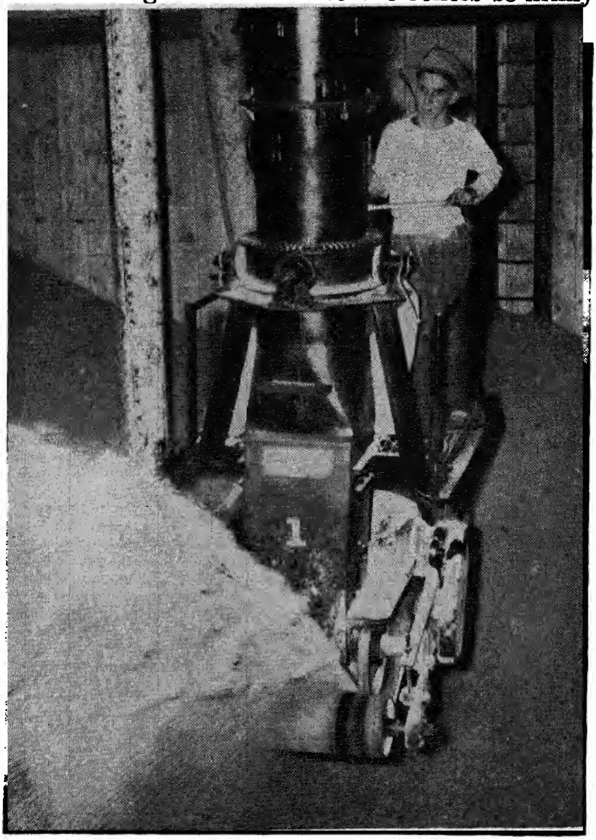


FIG. 10. Using a rubber-belt conveyor to load loose sugar into a ship's hold.

was started again, large strips of rubber were peeled off the back of the belt.

THE SOLUTION. Back at the factory, belting engineers developed a special belt having breaker strips at the top and bottom. These strips are loosely woven fabric plies that distribute the strain of sticky starts along the length of the belt instead of letting the rubber adjacent to the rollers take all the punishment. These improved belts proved immune to sweet glue and can load 400 tons of loose sugar an hour compared with the 80-ton hourly rate for bagged sugar.

The Case of the Almost Lost Coal Mine

The Problem. In Maryland there is a mine whose 450-foot depth contains a lot of coal and a lot of water. Pumps and a maze of pipes were installed to keep the water level down enough to permit miners to work. But the mine water contained acid, and soon the piping showed the

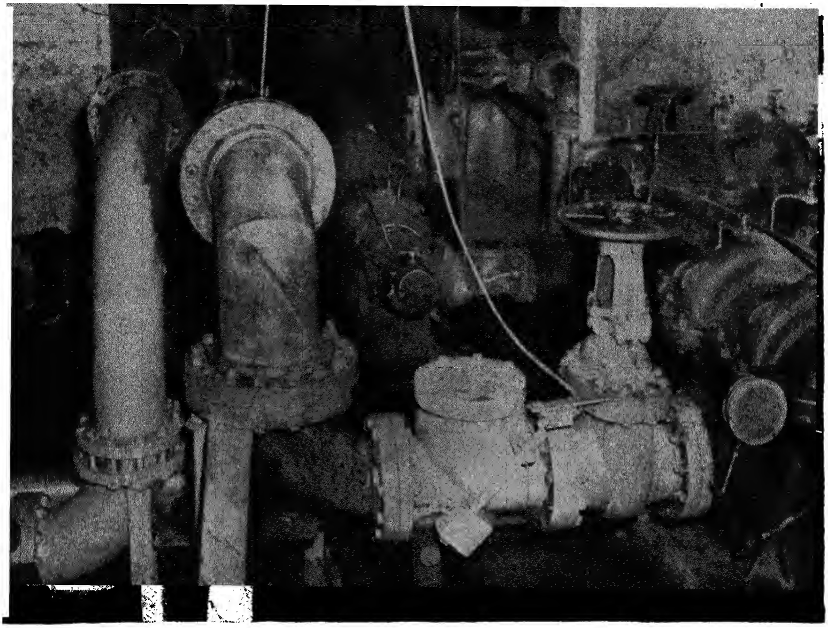


Fig. 11. Installation of rubber-lined pipe to carry acid-laden water out of a coal mine.

effects of corrosion. It looked for a while as if the pipes would fail faster than they could be replaced; and in three days, with pumps idle, the mine could fill with enough water to stop operations for months.

The Solution. The mine owner heard that chemical companies use steel pipes lined with rubber to carry all sorts of acids. He bought some of this rubber-lined pipe, installed it in his mine, and his worries about losing his diggings vanished. After four years, he compared notes. All-metal pipe used to be ready for the junk heap in 7 months. The rubber-lined pipe still looked as good as new after 48 months—although it had carried more than 10 billion gallons of acid water out of the mine.

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